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# The Functions and Design of Motor Vehicle License Plates

by

John E. Baerwald

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UNIVERSITY OF ILLINOIS BULLETIN

A REPORT OF AN INVESTIGATION

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THE DEPARTMENT OF CIVIL ENGINEERING
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## ABSTRACT

This comprehensive analysis of motor vehicle license plates was conducted with the following objectives:

1. To determine the functions of license plates and the relative importance of these functions.
2. To determine what information should be displayed on a license plate and the importance of each item of information.
3. To design the most effective and efficient license plate.

The study included the analysis of an opinion questionnaire, a literature search, and laboratory experiments conducted at the University of Illinois. This report provides the information necessary for the design of the most effective, efficient, and economical license plate, and for the design of a reflectorized license plate of maximum legibility.



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# I. INTRODUCTION

This comprehensive investigation of motor vehicle license plates was conducted by the Civil Engineering Department of the University of Illinois at the request of the Office of Charles F. Carpentier, Secretary of State, State of Illinois. The research was initiated in April, 1958, after an exploratory study revealed the need for an analysis of the functions and design of license plates.

Motor vehicle license plates are familiar objects in the Automobile Age. License plates of all types and sizes are displayed on motor vehicles in all parts of the world. Current plate designs feature a variety of colors, words, phrases, symbols, numbers, and letters — items which have been placed on the plate to accomplish various functions.

The number of motor vehicle registrations has risen rapidly in recent years, and this has caused license plates to become increasingly important. The adoption of new types of identification systems, the modification of older types, and the placement of publicizing slogans and symbols on plates by many states have created new problems in the design and arrangement of plate content. Several states are issuing plates with reflective backgrounds and legends in an effort to increase plate visibility and legibility. The combined effect of these new design considerations and the increased importance of license plates accentuates the need for a comprehensive study of motor vehicle license plates.

## A. OBJECTIVES OF THE STUDY

The investigations described in this report were conducted to determine the functions of license plates and the relative importance of the various functions; to determine what information should be placed on license plates and the relative importance of the various types of information; and to determine the best methods of presenting this information and design the most effective and efficient license plate.

## B. SCOPE OF THE STUDY

This study of motor vehicle license plates was conducted in two phases. Phase I was directed toward achieving the first two objectives, and Phase II was directed toward achieving the third.

In Phase I, the following possible functions of license plates were evaluated to determine their relative importance:

1. Exhibit information to show the individual vehicle identification.
2. Exhibit information necessary to show full compliance with the motor vehicle registration laws.
3. Exhibit information to show the area or county of residence of the motor vehicle owner.
4. Exhibit information to publicize and popularize the state.

Included in Phase I was a study of the importance of various types of license plate information. The items studied were:

1. Desired legibility distances for the registration number, state name, and year number.
2. Important characteristics of the registration number.
3. Importance of color in year identification.
4. Value of county or area identification.
5. The value of slogans in state identification.
6. Importance of two license plates.

Phase II was directed toward determining the best methods of presenting the required information on license plates. Plate design items studied were:

1. Plate size and shape.
2. Number and letter-number combinations.
3. Legibility of letters and numbers.
4. Size of state name and year numbers.
5. Effect of slogans on legibility.
6. Color combinations.
7. Miscellaneous factors such as registration

procedures, area identification, motor vehicle laws.

A study of reflective license plates was also conducted as a part of Phase II. The purpose of this study, in addition to investigating the effect of reflective license plates on nighttime motor vehicle collisions, was to investigate and prescribe criteria for a reflectorized license plate which will provide optimum legibility under daytime and nighttime traffic conditions. The variables of major concern were:

1. Character stroke width.
2. Character spacing.
3. Portion of the plate which is reflectorized.
4. Contrast direction (dark legend on light background and light legend on dark background).
5. Types of reflectorization material.
6. Color combinations.
7. Plate borders.

Motor vehicle administration procedures can influence the design of license plates. Although the effects of these procedures were often observed during this investigation, only those features are discussed herein which directly relate to and influence the main functions of license plates. Certain procedures such as local or regional distribution of license plates versus centralized distribution, issuance of plates for a use period of more than one year, and the adoption of reflectorized license plates, have administration and economic considerations which are beyond the scope of this investigation.

The procedure for each of the various studies is explained in the section of this report dealing with that investigation. In general, however, the procedure consisted of an extensive review of all available literature on the subject, application of the results and conclusions to license plates, and the conduct of additional field and laboratory tests necessary for valid conclusions.

# II. THE FUNCTIONS OF MOTOR VEHICLE LICENSE PLATES

A review of the license plate designs used by the states and provinces in the United States and Canada indicates that license plates are being used to carry many different items of information. Registration numbers and letters, county names, county or area code numbers or letters, congressional district numbers, state names, year numbers, state slogans, emblems, and weight indications are items currently found on passenger car plates. There is no general agreement concerning the important functions of license plates and the information required to accomplish these functions in accord with their relative importance.

This phase of the study was directed toward the determination of the functions or purposes of license plates and their relative importance. The study procedure, results, and conclusions were described and illustrated in detail in the progress report, "An Evaluation of the Purposes of the Purposes of Motor Vehicle License Plates,"[11]* transmitted to the Office of the Secretary of State in October, 1958. A summary of this initial phase of the study of motor vehicle license plates is presented in the following sections.

## A. STUDY PROCEDURE

To attain the data needed for this portion of the study, a questionnaire relating to the many items of license plate information was prepared and sent to 475 American and Canadian law enforcement officers, motor vehicle administrators, and officials who frequently use the information presented on license plates. Items included in the questionnaire were: number and placement of plates, desirable legibility distances, the vehicle registration number, year identification, county or area identification, and slogans or emblems.

Sixty-two percent of the questionnaires were completed and returned. The replies were tabulated, correlated to occupation, and analyzed to form the basis for the study conclusions.

* Numbers in superscript refer to the Bibliography.

## B. CONCLUSIONS

### 1. Functions of Plates

On the basis of the replies and comments received from the questionnaire distribution and from discussions with persons interested in the many facets of license plate design, the following conclusions concerning the functions of license plates were indicated:

a. The primary function of motor vehicle license plates is to display the information necessary for fast and accurate identification of a motor vehicle under actual traffic conditions. This function is accomplished by placing the individual registration number and the state name on the plate.

b. The second function of license plates is to display the information necessary to show compliance with the motor vehicle registration laws by the owner of the vehicle. This function is accomplished by placing the year number on the plate, by changing the color of the plate, and by using special designations for differing types and weights of vehicles.

c. The designation of the vehicle owner's county or area of residence is not a true function of license plates. In cases where distribution is on a county or local level, county or area designations may help in the enforcement of registration laws. In cases where identification is difficult and inaccurate due to the type of numbering system in use, the number of vehicle registrations, and other design considerations, county or area designations may facilitate the accomplishment of the function of identifying the vehicle quickly and accurately under actual traffic conditions. But county or area designations usually require more complex and costly administration procedures, especially in states where distribution is from a central office.

d. The advertising and publicizing of the state is not a function of license plates. Although such advertising may be of intangible value to the state, the placement of slogans and emblems on license plates tends to reduce the effective accomplishment of the important functions of license plates.

## 2. Necessary Characteristics of Plates

The answers and comments received from the questionnaire distribution, together with the considerations of plate size and methods of manufacturing, formed the basis for several conclusions regarding the characteristics of the information required on license plates to accomplish the functions of plates in accordance with their relative importance and by the most efficient methods.

a. For effective identification of motor vehicles under actual traffic conditions, each vehicle should be issued two plates, one to be displayed on the front of the vehicle and the other on the rear.

b. The vehicle registration number should be the most legible item of information on the plate, and should have the greatest legibility distance possible in consideration of plate size and design.

c. Research on license plate identification systems must continue to be directed toward the development of a system which possesses maximum legibility under actual traffic conditions. The system must also possess the characteristic of being easy to remember, but legibility is more important.

d. The year number should be legible at a distance approximately one-half that of the registration number.

e. The state name should be legible at a distance slightly greater than that required for reading the year number.

f. The year number is more important than the color combination in identifying the year of issuance of out-of-state plates. Cooperation and coordination among the states is necessary for color combinations to be of great help in identifying the year on out-of-state plates.

g. County or area designations, in the opinion of law enforcement officers, aid in fast and accurate identification of vehicles.

h. County or area designations usually require more complex and costly administrative procedures, especially in states where distribution is from a central office.

i. The county name is the least popular method of effecting a county designation.

j. The effect of address changes on the value of county and area designations is slight in states where new plates are issued annually. Where plates are renewed for one or more years, the harmful effect of address changes is greater.

k. County and area designations are of little value to persons outside the state of registration.

l. State slogans and emblems may have some value in the identification of the state.

m. The removal of state slogans from license plates and the use of the increased space for a larger state name would make state identification easier.

n. The removal of state slogans from license plates and the use of larger vehicle registration numbers could be a significant improvement in plate design.

It is emphasized that these conclusions are based primarily on the replies, comments, and opinions of law enforcement officers, motor vehicle administrators, and other persons interested in license plate information from throughout the United States and Canada and are not the result of specific testing and investigative procedures. Therefore, although the conclusions are considered to be valid, it is important to investigate the effect of varying circumstances in applying them to the licensing procedures of a particular state. These conclusions, however, served as important guides for license plate research directed toward the design of more effective and efficient license plates.

# III. THE VEHICLE REGISTRATION NUMBER

The primary function of motor vehicle license plates is to display the information necessary to identify the vehicle under actual traffic conditions. The individual vehicle registration number and the state name provide the information necessary for identifying the vehicle and its owner. The registration number, composed of letters, numbers, or both letters and numbers, must possess characteristics which facilitate rapid and accurate identification of a vehicle and its owner.

The combination of characters which make up the vehicle registration number must be perceived quickly and accurately, be legible at the required distance, and be readily adapted to simple, uniform, and efficient filing and administrative procedures. Additional research is needed to develop a registration system which lends itself to accurate transmission of license numbers over voice communication systems.

## A. THE PERCEPTION OF VARIOUS CHARACTER COMBINATIONS

The continued increase in the number of motor vehicle registrations and the increased speed of vehicular traffic accentuate the necessity for registration numbers which can be perceived quickly and accurately. Many states have adopted new identification systems in recent years, but in most cases the decision has been made with little attempt to determine the most desirable system.

### 1. Previous Studies

A literature search reveals a study of the perception of license plate legends conducted by M. H. Aldrich[1] in 1937. Mr. Aldrich's conclusions were:

For a short observation period (0.67 sec), five-digit numbers are decidedly superior to those with six, and six-digit plates are much more easily perceived than those with seven. Little would be gained by reducing the number of digits to four.

The introduction of letters increases errors in perception and the errors increase in proportion to the number of letters used. However, six-character plates with one letter are more easily perceived than seven-digit plates, and five-character plates with two letters are better than six-character plates with one letter.

There have been other studies of the "pure legibility" or legibility distance of license plates, but the study reported by Aldrich is the only perception study available.

A review of the registration systems used on license plates in the United States shows that there are many systems in use. States with registrations of approximately one million are using a combination of three letters and three numbers (which could provide more than seventeen million combinations) without evidence that this is a combination which can be perceived quickly and accurately with less difficulty than other combinations. Some states have adopted complex systems which cause letters and numbers to appear in various combinations and groupings without conducting prior tests to determine if simpler, more uniform combinations would be easier to perceive quickly and accurately.

### 2. Objectives

This project conducted extensive tests of the ease of perception of various combinations of letters and numbers with the following objectives: to determine the relative ease of perceiving various character combinations quickly and accurately; to determine the effect of letter position and separation of letters from numbers on the perception of letter-number combinations; to provide information for determining the best registration system for the State of Illinois on the basis of the test results; and to provide data which will allow other states to make decisions concerning the registration numbering system which they should use.

### 3. Study Procedure

Except for the research by Professor Aldrich,[1] most studies of license plates have studied the pure legibility of identification systems. The increasing high speed of traffic has, however, made fast and ac-

curate readability the determining factor in plate identification. Therefore, a test was designed to determine which combinations are easiest to perceive quickly and accurately.

These tests were conducted with the assumption that those number and letter-number combinations which are easiest to perceive quickly and accurately when exposed for a short interval of time in an indoor test would also be easiest to perceive quickly and accurately when displayed on license plates and read under actual traffic conditions. It was also assumed that those combinations which are most difficult to perceive quickly and accurately in an indoor test would have this same characteristic when viewed under actual traffic conditions.

The original assumption was that in the field the reading time is usually inadequate, which necessitates rapid, accurate observations. This reading is usually done by two different segments of our population: police officers, who, by profession, have become highly skilled at reading license plate characters, and members of the general public, who cannot be presumed to have this special ability.

Three possible perceptual situations exist in actual conditions: a stationary observer and a moving vehicle, a moving observer and a stationary vehicle, and a moving observer and a moving vehicle. It was assumed that more than half of the critical observations of license plates are made in the first two situations, where there is usually an extremely limited observation period.

Though the impossibility of determining critical reading times under actual field conditions was recognized, it was nevertheless necessary to choose some one exposure time for use during the study. It was assumed that the relative rank at one distance and one exposure period would apply at all distances, exposures, and levels of illumination. An exposure time of one-half second was chosen after preliminary tests indicated that observers could read and correctly record slightly more than 50% of the slides when they were exposed for this period. In any test situation the greatest difference between experimental conditions will be obtained when the overall average of test results is 50%.

A total of 128 test slides, illustrating sixteen combinations of numbers or letters and numbers, was prepared. The letters and numbers for each slide were chosen at random. The slides were designed so that the only variables were the number of letters, numbers, or both, and the grouping of

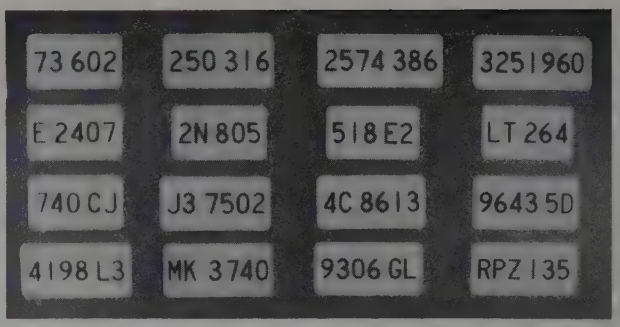



*Fig. 1. Examples of Character Combinations Used in the Perception Study*

the characters. When projected, the test plates had the following characteristics:

They were white, six inches high, and from 10⅜ in. to 13⅞ in. long, depending on the number of characters.

The numerals and letters were black, 2⅜ in. high, 1⅜ in. wide (except *1* and *I*), with a 5/16 in. stroke width.

Spacing between adjacent characters was ⅜ in.; between groups, 1 in.; and at the edges, ½ in.

The letters and numbers were centered vertically, and there was no year number, state name, slogan, or insignia.

Examples of the test combinations are shown in Fig. 1.

The following list indicates the general form of each of the sixteen combinations tested. In explanation: *12 345* means the plates in that group displayed two numbers, a space, and three numbers; *AB 123* is the general form for plates which had two letters, a space, and three numbers.

| *Group No.* | *General Form* |
|---|---|
| 1 | 12 345 |
| 2 | 123 456 |
| 3 | 1234 567 |
| 4 | 1234567 |
| 5 | A 1234 |
| 6 | 1A 234 |
| 7 | 123 A4 |
| 8 | AB 123 |
| 9 | 123 AB |
| 10 | A1 2345 |
| 11 | 1A 2345 |
| 12 | 1234 5A |
| 13 | 1234 A5 |
| 14 | AB 1234 |
| 15 | 1234 AB |
| 16 | ABC 123 |

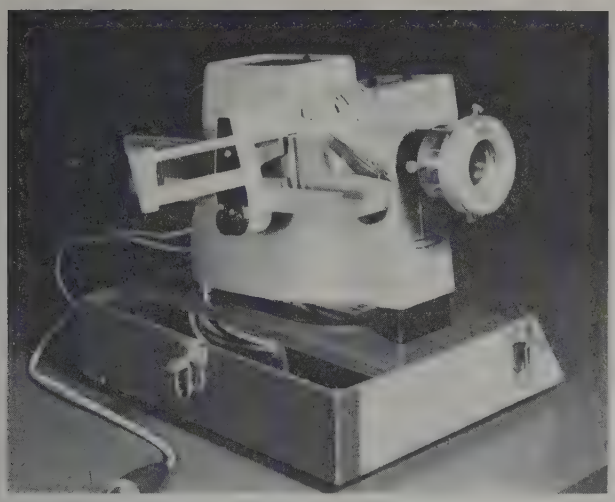


*Fig. 2. Slide Projector and Tachistoscope Used in Perception Tests*

The test was conducted in a darkened room using a 500-watt slide projector, an Ilex tachistoscope, and a 70 by 70-in. screen (see Fig. 2). The observers, usually three, four, or five, were seated at a table, 20 ft from the screen, with a data sheet and a pencil. They were briefed on the conduct of the test, informed that all slides would have five, six, or seven characters, and told that the letters and numbers might appear in any position. They were also told to record as much of what they had read as possible. Three sample viewings were made to acquaint the observers with the test procedure.

During the test each slide was exposed on the screen for one-half second. Following the exposure, the observers were given all the time they required to record their reading. The call "ready" meant that the next slide was about to be exposed.

The tests were conducted in thirty or forty minutes, depending on the speed of the observers, and were divided into three segments, with two or three-minute rest periods between segments. To offset the effects of familiarity with the test or of fatigue, the slides from the different groups were distributed throughout the test, and the order of presentation was reversed for half of the observers.

As recommended by the University of Illinois Department of Psychology, observers for the main portion of the experiment were chosen from one group — male college students. Because the objective of the test was the determination of the relative ease of perceiving various combinations of characters quickly and accurately, this decision appears justified. Observers from other age or occupational groups might be more or less proficient at reading combinations of characters, but it is expected that the relative ease or difficulty of perceiving various combinations quickly and accurately would remain almost constant for all groups.

Table 1

Results of Student Perception Tests

| General Form | Rank | Percentage Read Correctly |
|---|---|---|
| 12 345 | 1 | 92.0 |
| A 1234 | 2 | 90.8 |
| AB 123 | 3 | 89.8 |
| 123 AB | 4 | 86.8 |
| 123 A4 | 5 | 83.0 |
| 1A 234 | 6 | 80.4 |
| 123 456 | 7 | 75.0 |
| AB 1234 | 8 | 70.0 |
| 1234 AB | 9 | 58.8 |
| 1A 2345 | 10 | 58.6 |
| 1234 A5 | 11 | 55.6 |
| ABC 123 | 12 | 53.4 |
| A1 2345 | 13 | 51.0 |
| 1234 5A | 14 | 32.8 |
| 1234 567 | 15 | 28.9 |
| 1234567 | 16 | 26.0 |

To supplement the readings of the student observers, a limited number of police observers from the Champaign and Urbana City Police Departments, the University of Illinois Police, and the Illinois State Highway Police were also tested. Although it was anticipated that their readings would be influenced by familiarity with current license plate identification systems, police observers were tested to determine their proficiency in reading various character combinations.

The completed data sheet of each observer was checked to determine which slides were read correctly. The total number of slides read correctly in each of the sixteen groups was computed, and the scores of all observers averaged to determine the percentage of correct readings for each of the various combinations.

## 4. Results

Fifty male student observers were used in the perception tests, and these observers made a total of 6400 viewings of the test slides. The percentage of correct readings and the relative rank of the sixteen combinations tested are presented in Table 1.

The figures for "percentage read correctly" in Table 1 show a variation in perception ability from 92% to 26%. This indicates that the test procedure produced data which shows the degree of ease, or difficulty, with which a combination can be perceived quickly and accurately.

The results of the perception tests of certain combinations were analyzed by the Sign Test (22). The procedure is to determine the total number of

correct readings by each student of each of the two license combinations to be compared, and to note the positive or negative sign of the difference between the two totals. A plus sign is recorded if the observer correctly reads more of the first of the two types, a negative sign is recorded if more of the second type are read correctly, and a tie is recorded if an equal number of each type are read correctly. Hence, it is a sign test. The test procedure is to sum positive and negative signs, ignoring the ties which are uninformative, and test whether the signs are equally positive and negative. The null hypothesis tested by the sign test is that

$$\text{Prob.}\,(X_a > X_b) = \text{Prob.}\,(X_a < X_b) = .5\,,$$

where $X_a$ and $X_b$ are the totals of correct readings of the two different character combinations compared, using each student as his own control. Under the null hypothesis, we would expect the same number of positive signs as negative signs. The null hypothesis is rejected if too few of one sign occur.

The probability of getting as extreme an occurrence as 15 minus signs and 32 positive signs in a total of 47 pairs of comparison with 3 ties, for example, is given by the binomial distribution as

$$\text{Prob.}\,\{s \leq 15 \mid n = 47,\ p = .5\},$$

which is equal to

$$\begin{aligned} &1 - \text{Prob.}\,\{s \geq 15 + 1 \mid n = 47,\ p = .5\}^* \\ &= 1 - 0.990\ 688\ 1 \\ &= 0.009\ 311\ 9 \end{aligned}$$

for a one-tailed test, and

$$\begin{aligned} &2 \times 0.009\ 311\ 9 \\ &= 0.018\ 623\ 8 \end{aligned}$$

for a two-tailed test.

A one-tailed or two-tailed sign test is used as the situation dictates. In a one-tailed test, we expect on a priori grounds that one of the two signs will occur more frequently. In a two-tailed test, we expect that the frequencies with which the two signs occur will be statistically different, but which one of the signs will occur more frequently is either of no concern or beyond prima-facie evidence. Once the null hypothesis is rejected at the 1% level of significance,† we conclude from the test that we are in favor of the alternative hypothesis that one type of license combination is more easily perceived than the other.

**Table 2**

**Effect on Perception When Letters Are Substituted for Numerals**

In this table all-numerical combinations are compared with alpha-numerical combinations with the same number of total characters. In each of the three comparisons the all-numerical combination is favored with a statistically significant difference being observed in two comparisons.

| Combinations Compared | Number of Signs | | | Test Used | Prob.$\{s \leq r \mid n, p\}$ | Null Hypothesis Rejected at 1% Level of Significance |
|---|---|---|---|---|---|---|
| | + | − | Tie | | | |
| 12 345<br>1A 234 | 25 | 5 | 20 | One-tailed | 0.000 162 5 | Yes |
| 12 345<br>AB 123 | 20 | 8 | 22 | One-tailed | 0.017 849 1 | No |
| 123 456<br>ABC 123 | 36 | 7 | 7 | One-tailed | 0.000 004 5 | Yes |

The results of the sign tests are shown in Tables 2-6. These tables are arranged to show the relative perception accuracy of different character arrangements which are compared two at a time. The two combinations being compared are placed one above the other, with the upper one being the combination which was read correctly more often by a majority of the individual observers. A brief comment accompanies each table.

The results of the perception tests made with police observers are shown in Table 7. In considering the results of the police tests, the following is noted: (1) The number of observers was small, and the values could possibly change with additional observers, rearranging the rankings. (2) All policemen tested were from east-central Illinois and are most familiar with the Illinois system of one to seven numbers and the Indiana system of two letters-one to four numbers. (3) The police observers were accustomed to reading those combinations which are currently in use but unaccustomed to reading those which differ from current practice.

In general, the results of the tests with police observers are similar to the results of the student tests. The police, however, were more proficient at reading the straight numerical combinations and the combinations of two letters and three or four numbers. This was probably due to their experience in reading Illinois and Indiana plates. The police observers were less proficient with those combinations which had letters at the end. In this case, their lack of familiarity with those combinations was probably responsible.

The results of the tests with police observers

* The probability in the bracket is obtained by reading Table 2, National Bureau of Standards, U. S. Department of Commerce, *Tables of the Binomial Probability Distribution*, Applied Mathematics Series 6. Washington D.C.: U. S. Government Printing Office (1950).

† Considering the total number of observations made, the probability is one chance in one hundred that difference of this size could have occurred by chance.

Table 3

Effect on Perception When the Number of Characters Is Increased

Each of the eight comparisons shown in this table indicates a statistically significant difference in the glance perception of a five or six character combination when a numeral or letter is added to the combination (i.e. AB 123 is easier to read during a brief reading time than AB 1234, 123 456 is easier to read than 1234 567, etc.)

| Difference in Combinations Being Compared | Combinations Compared | Number of Signs | | | Test Used | Prob. $\{s \leq r \mid n, p\}$ | Null Hypothesis Rejected at 1% Level of Significance |
|---|---|---|---|---|---|---|---|
| | | + | − | Tie | | | |
| Variable Number of Numerals and Total Number of Characters | AB 123<br>AB 1234 | 36 | 2 | 12 | One-tailed | 0 | Yes |
| | 1A 234<br>1A 2345 | 36 | 4 | 10 | One-tailed | 0.000 000 1 | Yes |
| | 123 A4<br>1234 A5 | 36 | 4 | 10 | One-tailed | 0.000 000 1 | Yes |
| | 123 AB<br>1234 AB | 38 | 2 | 10 | One-tailed | 0 | Yes |
| | 12 345<br>123 456 | 35 | 3 | 12 | One-tailed | 0 | Yes |
| | 123 456<br>1234 567 | 48 | 1 | 1 | One-tailed | 0 | Yes |
| Variable Number of Letters and Total Number of Characters | A 1234<br>AB 1234 | 39 | 2 | 9 | One-tailed | 0 | Yes |
| | AB 123<br>ABC 123 | 44 | 0 | 6 | One-tailed | 0 | Yes |

Table 4

Effect on Perception When a Letter Group Replaces a Numeral-Letter Group
or
A Numeral Group Containing One Additional Character

The comparisons made in the upper part of this table favor the two letter group over the letter-number group. Although only two of the indicated comparisons led to the observation of a statistically significant difference, the fact that all six comparisons favor the combinations with a pair of letters rather than a number-letter pair is itself almost statistically significant. In the middle part of the table statistically significant differences are shown when the two letter group replaces the three numeral group. The lower part comparison shows a statistically significant difference when a three letter group replaces a four numeral group.

| Difference in Combinations Being Compared | Combinations Compared | Number of Signs | | | Test Used | Prob. $\{s \leq r \mid n, p\}$ | Null Hypothesis Rejected at 1% Level of Significance |
|---|---|---|---|---|---|---|---|
| | | + | − | Tie | | | |
| Two Letter Group Versus Letter-Number Group | AB 123<br>1A 234 | 25 | 11 | 14 | Two-tailed | 0.028 816 8 | No |
| | AB 1234<br>1A 2345 | 32 | 15 | 3 | Two-tailed | 0.018 623 8 | No |
| | AB 1234<br>A1 2345 | 38 | 4 | 8 | Two-tailed | 0 | Yes |
| | 1234 AB<br>1234 A5 | 18 | 16 | 16 | Two-tailed | 0.864 166 2 | No |
| | 1234 AB<br>1234 5A | 37 | 3 | 10 | Two-tailed | 0 | Yes |
| | 123 AB<br>123 A4 | 20 | 8 | 22 | Two-tailed | 0.035 698 2 | No |
| Two Letter Group Versus Three Numeral Group | AB 123<br>123 456 | 33 | 5 | 12 | One-tailed | 0.000 002 1 | Yes |
| | 1234 AB<br>1234 567 | 39 | 6 | 5 | One-tailed | 0.000 000 3 | Yes |
| Three Letter Versus Four Numeral Group | ABC 123<br>1234 567 | 36 | 4 | 10 | Two-tailed | 0.000 000 2 | Yes |

suggest the desire for a certain degree of uniformity in the identification systems used by all the states. All combinations of letters and numbers should be properly grouped and spaced, letters should always appear at the beginning or end and be separated from the numbers, and, so far as possible, all states should use the same identification system. If this were done, the police and the public would be able to read out-of-state plates with the same degree of proficiency as they read plates from their own states.

## 5. Conclusions

The results of the perception tests with student

Table 5

Effect on Perception When the Position of Letters Is Varied

The first section of this table shows four comparisons where the letter group is placed in the beginning or end position of the character combination. Although the results of these comparisons are inconclusive, they suggest that the two letter groups be placed in the beginning position. The second section comparisons favor the placement of a single letter next to the space between the groups.

| Difference in Combinations Being Compared | Combinations Compared | Number of Signs | | | Test Used | Prob. $\{s \leq r \mid n, p\}$ | Null Hypothesis Rejected at 1% Level of Significance |
|---|---|---|---|---|---|---|---|
| | | + | − | Tie | | | |
| Letter Block in First Position Versus Letter Block in Second Position | 1A 2345<br>1234 5A | 39 | 2 | 9 | Two-tailed | 0 | Yes |
| | 1234 A5<br>A1 2345 | 22 | 14 | 14 | Two-tailed | 0.242 985 0 | No |
| | AB 123<br>123 AB | 16 | 15 | 19 | Two-tailed | 1.000 000 0 | No |
| | AB 1234<br>1234 AB | 27 | 12 | 11 | Two-tailed | 0.023 702 8 | No |
| Letter Next to Space Versus Letter at End | 1A 2345<br>A1 2345 | 27 | 11 | 12 | Two-tailed | 0.013 853 0 | No |
| | 1234 A5<br>1234 5A | 34 | 4 | 12 | Two-tailed | 0.000 000 6 | Yes |

Table 6

Effect of the Spacing of Seven Numerals on Perception

This table shows a comparison of two combinations of seven numerals, one with characters equally spaced and the other with the characters in groups of four and three. Although the test results are not statistically significant the grouping of the characters is favored.

| Combinations Compared | Number of Signs | | | Test Used | Prob. $\{s \leq r \mid n, p\}$ | Null Hypothesis Rejected at 1% Level of Significance |
|---|---|---|---|---|---|---|
| | + | − | Tie | | | |
| 1234 567<br>1234567 | 27 | 16 | 7 | Two-tailed | 0.126 289 4 | No |

Table 7

Results of Police Perception Tests (15 observers)

| General Form | Rank | Percentage Read Correctly |
|---|---|---|
| 12 345 | 1 | 98.7 |
| AB 123 | 2 | 92.7 |
| A 1234 | 3 | 89.4 |
| 1A 234 | 4 | 82.7 |
| 123 AB | 4 | 82.7 |
| 123 456 | 4 | 82.7 |
| AB 1234 | 7 | 82.0 |
| 123 A4 | 8 | 79.4 |
| 1A 2345 | 9 | 58.0 |
| A1 2345 | 10 | 47.3 |
| 1234 567 | 11 | 42.2 |
| ABC 123 | 12 | 40.7 |
| 1234 AB | 13 | 38.7 |
| 1234 A5 | 14 | 36.0 |
| 1234 567 | 15 | 30.7 |
| 1234 5A | 16 | 21.3 |

observers form the basis for the following conclusions concerning the characteristics which affect the fast, accurate perception of combinations of characters:

a. Perception is, in general, made more difficult by the addition of a character to an existing combination of numerals or numerals and letters. Therefore, the total number of characters in a registration system should be kept to a minimum.

b. In general, an increase in the number of letters in a combination with a fixed number of characters increases the difficulty of fast, accurate perception.

c. Perception is affected by the manner in which characters are grouped. Grouping the letters and separating them from the numerals improves perception.

d. The use of a group of two or three letters to replace a group of three of four numerals, respectively, is an acceptable way to minimize the total number of characters in a registration system.

e. Uniformity in the placement of letters in letter-number combinations would aid fast, accurate perception. Letters, when used, should be at the front of the combination, at least until further evidence might suggest this to be undesirable.

f. Additional research should be initiated to determine which registration combinations can be most accurately transmitted over voice communication systems.

## B. THE LEGIBILITY DISTANCE OF LETTERS AND NUMBERS

The combination of characters used to make up the vehicle registration number should possess characteristics which make the characters legible at a desirable distance. The desired daytime legibility distance of the registration number, while an arbitrary figure, is generally in the range of 100 to 150 ft. Wiley[27] stated, "In a well designed plate, the license number should have a legibility distance in daylight of at least 125 ft."

Many factors not related to character design affect the legibility distance of letters or numbers, but this investigation was directed toward deter-

Table 8

Height and Width of Characters Used on License Plates

| State | Character Height (in.) | Character Width (in.) | Height-Width Ratio |
|---|---|---|---|
| Florida | 2¾ | 1 | 2.75:1 |
| South Carolina | 3 1/16 | 1⅛ | 2.72:1 |
| Idaho | 3¼ | 1¼ | 2.60:1 |
| New Mexico | 2⅜ | 1⅛ | 2.56:1 |
| Oklahoma | 3⅛ | 1¼ | 2.50:1 |
| Illinois | 3 | 1¼ | 2.40:1 |

mining the characteristics of letters and numbers which affect legibility distance. This information can then be used as a guide in the selection of letters and numbers which possess desirable characteristics and a satisfactory legibility distance.

### 1. Characteristics Which Affect Legibility

a. Height and Width of Characters

There is a definite correlation between the height of characters and their legibility. Forbes and Holmes[7] suggest that the relationship between letter height and distance is not linear; that is, uniform increases in letter height do not result in equal increases in legibility distance. Matson *et al.*[17] say that "legibility distances increase curvilinearly with letter height for a given series in the smaller letters, and linearly in large letters." Regardless of the relationship, an increase in character height results in an increased legibility distance, provided that the width of the character increases proportionately.

The daylight legibility per inch of letter height of the U. S. Bureau of Public Roads alphabets as shown in Fig. 3 has been reported as follows: Series B — 33 ft per in., Series C — 42 ft per in., and Series D — 50 ft per in.[17]

Soar,[23] in a study in which he analyzed two styles of characters, each with four height-to-width ratios, prescribes 1.33:1 as an optimum height-to-width ratio. Dr. A. R. Lauer, in an unpublished memorandum, indicates that the legibility distance increases as the height-width ratio approaches unity.

The references studied suggest that the height-to-width ratio of a character is an important determinant in its legibility distance, and that there is a correlation between the height of its character and its legibility.

A review of the dimensions of numbers and letters currently used on license plates shows that, in general, their height-to-width ratio is too large. Table 8 presents the dimensions of characters used on 1958 plates in states which use characters with a large height-width ratio. These plates are shown in Fig. 4.

Table 9

Effect of Stroke Width on Legibility of Numbers

| Stroke Width (in.) | Legibility Distance (ft) White on Blue | Blue on White |
|---|---|---|
| 7/16 | 112.4 | 107.3 |
| ⅜ | 109.8 | 103.1 |
| 5/16 | 110.2 | 100.1 |
| ¼ | 109.5 | 98.4 |

Fig. 3 illustrates the effect of decreasing the height-to-width ratio while holding the height of the characters constant. The numbers illustrated are Bureau of Public Roads Series A, B, C, and D. The dimensions of the numbers are:

| *Series* | *Height (in.)* | *Width (in.)* | *Height-Width Ratio* |
|---|---|---|---|
| A | 3 | 1 1/8 | 2.67:1 |
| B | 3 | 1 17/64 | 2.37:1 |
| C | 3 | 1 41/64 | 1.83:1 |
| D | 3 | 2 1/64 | 1.49:1 |

As a general guide, the height-to-width ratio of characters used on license plates should be reduced to 2:1 or less, if possible. The present standard 12-in. plate limits the width of characters to approximately 1⅜ in. when six characters are used with correct spacing and grouping. It would appear, then, that as long as the standard plate size remains 6 by 12 in., the letters and numbers used as part of the vehicle registration number should have approximately the following dimensions: height, 2½ to 3 in., and width, 1¼ to 1¾ in.

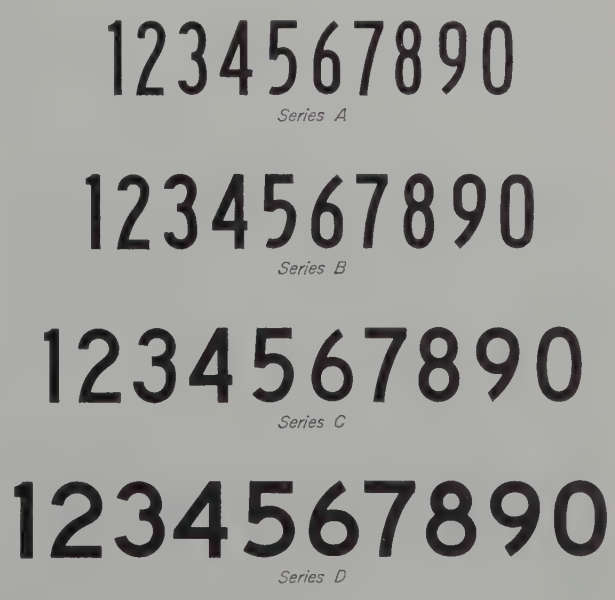



*Figure 3*
*The Effect of Decreasing the Height-Width Ratio While Holding the Height of the Characters Constant*

b. Stroke Width

The optimum stroke width of a character is dependent on its height and width and on the colors of the character and plate background. The reporting of stroke width determinations is generally done with respect to the height of the character and its stroke width ($H/SW$). The height is measured from the centers of the top and bottom horizontal strokes.

Kuntz,[12] in a very thorough study concerning stroke widths, says the optimum height-to-stroke-width ratio is 5.0:1, but that the difference between 5.0:1 and 6.0:1 or 4.0:1 is not significant. This would indicate a range of ratios wherein differences in legibility would be negligible. The Bureau of Public Roads varies the stroke width for each of its series of alphabets. The list below indicates the $H/SW$ ratios recommended by them:

| *Series* | *A* | *B* | *C* | *D* | *E* | *F* |
|---|---|---|---|---|---|---|
| $H/SW$ Ratio | 11:1 | 8:1 | 7:1 | 6.5:1 | 6:1 | 5:1 |

A Series C number, therefore, with an overall height of 3 in. and a stroke width of $\frac{3}{8}$ in., would have an $H/SW$ ratio of

$$\frac{(3) - (\frac{3}{8})}{(\frac{3}{8})} = 7.0{:}1.$$

As a portion of the study of reflectorized plates, the effect of stroke width on legibility was studied for 3-in. white painted numerals on blue painted backgrounds and for 3-in. blue painted numerals on white painted backgrounds. The study procedure is described in detail in a later section of this bulletin. Pure legibility tests were conducted in a darkened indoor area with the plates illuminated with low beams of a standard headlight system. The results of the tests with regular painted plates are presented in Table 9.

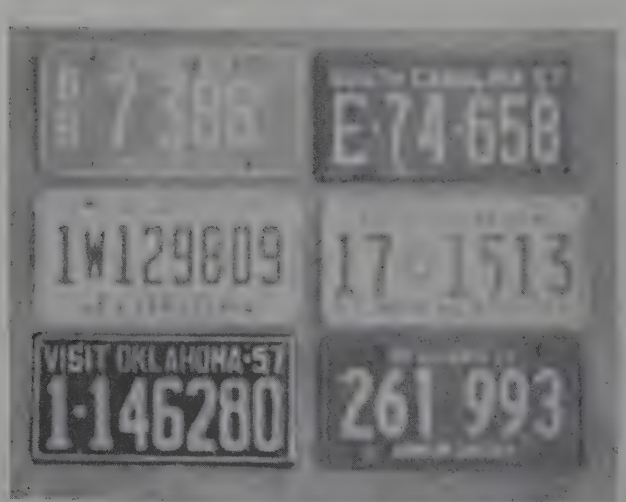



*Fig. 4. Examples of Characters with a Large Height-Width Ratio*

The results of these legibility studies with painted plates show the effect of stroke width on legibility. With a white background, decreasing stroke width reduced the legibility distance, probably because the numbers "faded" into the background. With white numerals, however, the reduction in stroke width did not reduce the legibility distance materially. However, as explained in a later section, the space between numbers on these test plates was large. Close spacing would tend to cause white numbers to merge and become illegible when their stroke width was large.

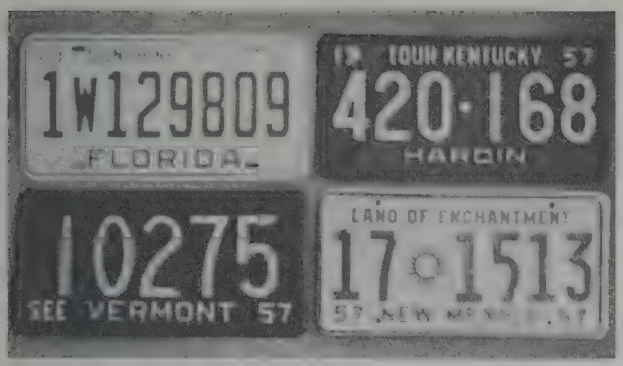
In view of the results of these studies, and with due consideration for the effects of spacing, it appears that characters used on painted plates should have an $H/SW$ ratio similar to that of the Bureau of Public Roads Series C alphabet — 7:1. Assuming a height-to-width ratio of approximately 2:1, 2-in. characters should have a stroke width of $\frac{1}{4}$ in.; $2\frac{1}{2}$-in. characters, $\frac{5}{16}$ in.; and 3-in. characters, $\frac{3}{8}$ in. These values are general guides, subject to change when the height-to-width ratio is significantly greater or less than 2:1.

c. Letter and Number Style

There are many factors involved in the determination of an optimum character styling, but the most important are the simplicity or complexity of the character outline, the amount of open space within the outline of the character, and the emphasis on one component of the character which differentiates it from another.

Character styles can be grouped into three general categories; block, rounded block, and open. Fig. 5 illustrates these styles. In his study of highway signs, Neal[18] says that rounded letters are more visible than block and do not tend to run together as much when they are closely spaced. Aldrich[1] stated that the open style of numeral is more visible than either the round or block. His limited legibility tests gave the following average legibility distances for 3-in. numbers with $\frac{3}{8}$-in. stroke: open, 154 ft; round, 141 ft; and block, 138 ft. According to Maston *et al.*,[17] the rounded block style letters yield about 5% greater legibility distance than pure block capital letters.

Currently, license plates from almost every



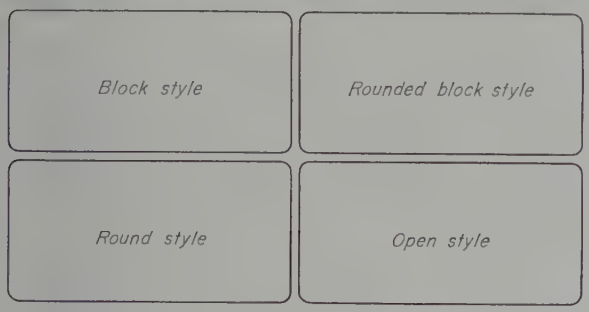




*Fig. 5. Typical Character Styles Used on 1957 License Plates*

state use a different character style. While it does not appear necessary that every state use the same style, those states which use block characters or characters with an unusual style should adopt some version of the open or round style. This would eliminate the similarity between characters which results from use of block characters and would prevent the confusion which results when attempting to read characters with a highly unusual style. Character styles should be similar to the Bureau of Public Roads Series B or C alphabets or the American Association of Motor Vehicle Administrators' standard alphabet for license plates.

d. Spacing

It is generally agreed that the spacing between the characters on a license plate is an important consideration when studying legibility and that generous spacing is advantageous.

The method of manufacturing license plates requires that the dies used for all characters be of equal width and that the characters within a group have a uniform center-to-center spacing. Generally, therefore, characters are designed so that they all have the same width (except the *1* and the *I*) and the same size of space between the extremities of adjacent characters.

The Bureau of Public Roads recommends that the spacing vary from 1.2 times the stroke width for parallel strokes to almost zero for strokes of opposing slope. Neu[19] attacked the problem from the standpoint of the limitations of the human eye and presented a formula for determining the minimum spacing between parallel lines. This formula is

$$S = 0.0035D$$

where $S$ is the required spacing in inches between the parallel lines and $D$ is the required legibility distance in feet. For a minimum legibility distance of 150 ft, the minimum spacing is computed to be about ½ in. These values are for painted surfaces. When reflective surfaces are used, spacing requirements vary. This subject is covered in a later section of this bulletin.

The references cited indicate that: (1) the spacing between characters on current license plates is too small; (2) spacing requirements vary with the size and shape of character; (3) for a legibility distance of 150 ft, spacing between characters on painted plates should be approximately ½ in.; and (4) the spacing of characters on reflectorized plates must be considered separately.

e. Conclusions

The results of various legibility studies, together with the results of the studies reported in this bulletin, suggest the following conclusions regarding the characteristics of the letters and numbers used in the vehicle registration number.

To achieve a legibility distance of approximately 125 ft, characters should have the following approximate dimensions: height 2¾ to 3¼ in., width 1¼ to 1¾ in., stroke width 5/16 to ⅜ in.

The height-to-width ratio of characters should be approximately 2:1. The ratio of height-to-stroke width should be approximately 7:1.

The style of character used should be open or round. Block style characters should not be used because of the similarity between many block characters. Highly unusual styles should be avoided because of their tendency to confuse the observer.

Adjacent characters should have a space of ⅜ to ½ in. between their extremities.

## 2. Specific Character Legibility

Certain letters and numbers are less legible than others because of similarity in form. In choosing letters and numbers for use in the vehicle registration number, it may be necessary to eliminate those characters which are least legible. There have been

several studies of the relative legibility of characters, and the results of those studies, together with the data obtained in the University of Illinois legibility tests, will form the basis for decisions regarding which characters are best for use on license plates.

a. Previous Studies

In his study of the legibility of numerals, Kuntz[12] stated that those numerals having the most curved lines are least legible, due to their similarity of form. The order of legibility according to his data was *1, 7, 0, 4, 3, 2, 9, 6, 5,* and *8.*

Aldrich[1] noted that the digits which were confused least were *1, 2, 4, 5, 6, 7,* and *0.* The digits *3, 8,* and *9* were confused most. He also noted that a *3* with a flat top was found to be "very bad," being easily confused with a *5.*

A table of the relative legibility of the letters was devised by Neu[19] in which he compared the legibility of all the letters of the alphabet with "E" as a standard. The following list presents the relative legibility values.

| | | | |
|---|---|---|---|
| A — 1.30 | H — 0.92 | O — 1.05 | V — 1.03 |
| B — 0.85 | I — 1.41 | P — 1.04 | W — 1.13 |
| C — 1.07 | J — 1.04 | Q — 1.05 | X — 1.08 |
| D — 1.03 | K — 1.05 | R — 0.97 | Y — 1.04 |
| E — 1.00 | L — 1.19 | S — 0.95 | Z — 1.01 |
| F — 1.04 | M — 1.13 | T — 1.15 | |
| G — 0.92 | N — 1.00 | U — 1.07 | |

The legibility of letters will vary with the letter style, size, and shape, but the relative legibility values presented by Neu can serve as a guide in the choice of letters. His values show *A, I, L,* and *T* to be the most legible and *B, H,* and *G* to be least legible. All others are in the group of fair legibility.

b. The University of Illinois Study

Although previous studies have verified the conclusion that some numbers or letters are more legible than others, there is no conclusive evidence that either letters or numbers are, in general, more legible.

A pure legibility test, using twenty test plates bearing either all numbers or all letters, was conducted to determine the relative legibility of groups of letters and numbers. Numbers used were from the Bureau of Public Roads Series B — 3 in. high and $1\frac{7}{64}$ in. wide, with a $\frac{3}{8}$-in. stroke. The letters used were modified Series B — 3 in. high, with a $\frac{3}{8}$-in. stroke. The width of the letters varied from $1\frac{1}{4}$ in. to $1\frac{1}{2}$ in. All characters were centered on the test plate with $\frac{1}{2}$-in. spacing between adjacent characters. All of these test plates carried white characters on a blue background and were of the standard size, 6 by 12 in.

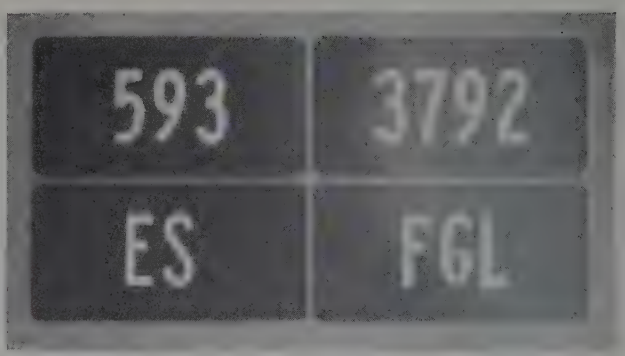



*Fig. 6. Test Plates Used in Letter and Number Legibility Tests*

The test plates which displayed numbers were prepared in two groups. Group A plates displayed three numbers and Group B plates displayed four numbers. To neutralize the effects of number difficulty, the number combinations for both series were chosen according to the results of legibility studies made with painted plates as part of the study of the effect of reflective plates.

The test plates which carried letters were also prepared in two groups. Group C plates displayed two letters and Group D plates displayed three letters. The letters used in each series were chosen according to the relative legibility values reported by Neu.[19] The average relative legibility of the letters used in both Groups C and D was 1.057, which is the average relative legibility for all the letters as reported by Neu. Examples of the test plates prepared for Groups A, B, C, and D are shown in Fig. 6.

For purposes of comparison, three actual license plates were added to the test. The plates were: (1) a 1956 California plate carrying three letters and three numbers with black characters and a yellow background, (2) a 1957 Wisconsin plate carrying two letters and four numbers with black characters and a yellow background, and (3) a 1957 Indiana plate carrying two letters and four numbers with blue characters and a gold background.

The test was conducted in an indoor area under controlled artificial lighting. Test plates were displayed on a cart which advanced toward the ob-

Table 10

Results of Letter and Number Legibility Tests

| Plate Description | No. of Test Plates | No. of Observations | Average Legibility Distance (ft) |
|---|---|---|---|
| Group A (three numerals) | 5 | 60 | 136 |
| Group B (four numerals) | 5 | 60 | 129 |
| Group C (two letters) | 5 | 60 | 124 |
| Group D (three letters) | 5 | 60 | 111 |
| 1956 California *NWB 872* | 1 | 12 | 95 |
| | 1 | 12 | 110 |
| 1957 Wisconsin *AK 9679* | 1 | 12 | 110 |
| | 1 | 12 | 120 |
| 1957 Indiana *XY 6779* | 1 | 12 | 99 |
| | 1 | 12 | 103 |

Table 11

Results of Student's "t" Tests on Legibility Data

| Plate Groups Compared | Average Legibility Distance | Difference in Legibility Distances | "t" Value | Means Differ Significantly | Confidence Level |
|---|---|---|---|---|---|
| A | 136′ | 25′ | 5.20 | Yes | .01 |
| D | 111′ | | | | |
| A | 136 | 12 | 2.17 | Yes | .05 |
| C | 124 | | | | |
| B | 129 | 18 | 5.62 | Yes | .01 |
| D | 111 | | | | |
| B | 129 | 5 | 0.98 | No | ... |
| C | 124 | | | | |
| C | 124 | 13 | 2.43 | Yes | .02 |
| D | 111 | | | | |
| A | 136 | 7 | 1.55 | No | ... |
| B | 129 | | | | |

server at a constant rate of approximately 1 ft per sec. The observer was instructed to read aloud what he thought the characters on the plate were. When all characters had been correctly identified, the legibility distance was recorded on the data sheet by the recorder, and the cart was returned to the starting position for the test plate. Only one legibility distance was recorded for those plates which carried all letters or all numbers — the distance at which all characters were correctly identified. Two distances were recorded for the three actual plates: (1) the distance at which all letters were read correctly and (2) the distance at which all numbers were read correctly. Twelve observers, nine male and three female, viewed the test plates and made a total of 312 observations.

The results of the legibility distance tests are presented in Table 10. The date was analyzed by Student's "t" test to determine the statistical significance of the differences between the legibility distances of the various groups of plates. The Student's "t" test values may be found in Table 11.

The results of these legibility tests show that letters are not legible at as great a distance as numbers. Group A plates (three numerals) were legible at a 22.5% greater distance than Group D plates (three letters). Group A plates were also legible at a distance 9.7% greater than Group C plates (two letters). Plates with four numerals (Group B) were 16.3% more legible than Group D plates with three letters. The difference in legibility distances between Group B and Group C was not significant. When all conditions are equal, letters do not have as large a legibility distance as numbers because, as Professor Wiley[27] stated, "There are more letters than numbers and many letters are very similar."

The test results also indicate that increasing the number of characters in a group reduces the legibility distance. Plates with two letters (Group C) were legible at a distance 11.7% greater than plates with three letters (Group D). Group A plates were legible at a distance 5.4% greater than Group B plates, but this difference was not statistically significant. These results emphasize the importance of grouping characters on license plates. For example, an observer can read two groups of three characters easier than one group of six characters.

The legibility distances of the letters and numbers on the actual California, Wisconsin, and Indiana plates substantiate the results of the tests with the special test plates. Although the letters were placed at the front on all three actual plates, and on the California plate were wider than the numbers, the average legibility distances of the numbers were greater than those of the letters.

In a previous section of this bulletin it was concluded that it is desirable to use a minimum number of characters in the vehicle registration number. A practical length of license plate, 12 in. or 14 in., suggests a maximum of six characters. When vehicle registrations exceed one million, the use of letters and numerals in the registration number is necessary if the use of seven characters is to be avoided. Letters used in letter-number combinations must be designed so that they will have legibility distances equal to that of numbers. Professor Wiley [27] stated, "For balanced legibility, the letters should be somewhat larger than the numbers."

Assuming a linear relationship between legibility distance and letter height, and using the legibility distance values from Table 10, we find that letters in groups of three should be 22.5% larger than numbers in groups of three.

$$\left(\frac{129 - 111}{111}\right) \times 100 = 22.5\%$$

Similarly, letters in groups of two should be 4% larger than numbers in groups of four,

$$\left(\frac{129 - 124}{124}\right) \times 100 = 4\%,$$

and 9.7% larger than numbers in groups of three.

$$\left(\frac{136 - 124}{124}\right) \times 100 = 9.7\%$$

c. Conclusions

The results of the legibility distance tests, together with the information obtained from previous studies, form the basis for the following conclusions:

When viewed under the same conditions, letters on the average are not legible at as great a distance as numbers when both are of the same size and style.

An increase in the number of characters in a group reduces the legibility distance for both letters and numbers.

The number of letters used on license plates should be restricted to the minimum number required for fast and accurate perception of the registration number.

Letters used on license plates should be designed so that they are nearly equal in legibility to numbers. They should be taller and wider than numbers.

Letters used on license plates should be designed so that individual letters are distinctive and not similar in form to other letters. Block letters should be avoided.

## C. ADDITIONAL CONSIDERATIONS

In addition to possessing characteristics which allow it to be perceived quickly and accurately at the required distance, the vehicle registration number should be readily adapted to various administrative and filing procedures. In some states, a part of the registration number consists of a code identification for a particular area or county.

### 1. Motor Vehicle Records

It is extremely important that the vehicle identification numbering system be easily adapted to efficient filing procedures. Information must be taken from the motor vehicle files in response to police inquiries, and the replies must be fast and accurate. Uniformity in the identification system is an aid in the maintenance of files which can be used quickly and accurately. If the identification numbering system is purely numerical, or if an identification system contains letters which are always in the same position (preferably at the front), filing problems are minimized. When letters and numbers are permitted to appear in any position or combination, the maintenance of efficient records can become a difficult problem.

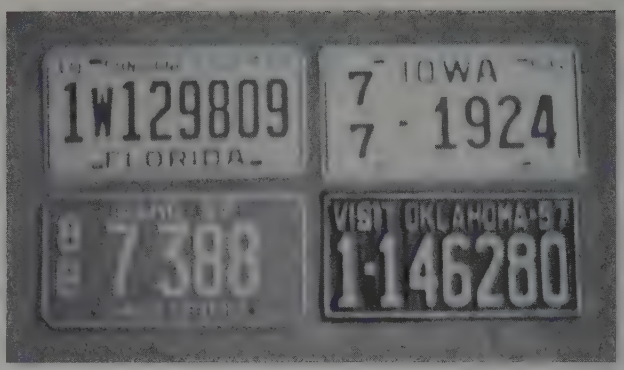



*Fig. 7. Examples of Plates with Crowded Legends and Small Characters*

### 2. Area Identification

Certain states, especially those which issue plates through county or district offices, place some form of area code in their vehicle registration number. In some states (Iowa, Idaho, Florida, Alabama, and others) the desire to retain a county or area code has forced a reduction in the size of the vehicle identification numbers, or has resulted in a crowded plate design as shown in Fig. 7.

In Phase I of this research study, law enforcement officers were of the opinion that these area designations could be helpful in fast and accurate vehicle identification. It is obvious, however, that a reduction of the size of the registration numbers, coupled with a necessary increase in the total number of characters when an area designation is used, will reduce the speed and accuracy of vehicle identification. States which issue plates with area designations should use a coding system which will keep the total number of characters to six or less, or else the value of the area code is lost because of imperceptible and illegible registration numbers.

### 3. Traffic and Marketing Studies

License plate registration numbers are observed and recorded by numerous agencies in connection with traffic and marketing studies. The registration number, if possible, should possess certain characteristics to facilitate the conduct of these studies.

Many traffic studies record the last three or four characters of the registration number. To facilitate

accurate identification of the vehicle, it is important that the identification system have characteristics of uniformity so that the observer will know in advance whether the characters he is to read will always be letters or numbers. A system which uses letters and numbers in any combination or position forces the observer to make two decisions: (1) is it a letter or number and (2) which letter or number is it?

Marketing studies are similar to traffic studies in many respects, and in addition they often require the entire registration number so that the name and address of the owner may be traced. This requires registration characters which can be read quickly and accurately because the observations are usually made from a stationary position. Area identifications are often helpful in these studies.

#### 4. Identification of Trucks and Special Vehicles

The investigation of the suitability of various combinations of characters for use in vehicle identification systems has been conducted primarily with reference to automobile plates, because automobiles are by far the largest class of motor vehicles. The results of the investigation can also be applied to the choice of suitable identification systems for other classes of vehicles.

According to *Automobile Facts and Figures, 1958 Edition,* the total truck registration in the United States in 1957 was 10.49 million and the total automobile registration was 55.69 million. Each state divides trucks into several classes, generally by weight, and licenses them accordingly. Truck license plates must carry some designation to show that the proper plate is carried, and many states use letters to indicate the various classes.

The use of a classification letter or letters for trucks appears to be a satisfactory procedure. As with passenger plates, the letters should be larger than the numbers and separated from the numbers. To eliminate confusion, it would appear desirable to place the classification letter or letters at the end of the combination, especially where truck plates are of the same color combination as passenger car plates.

Depending on state practice, special registration series are issued other types of vehicles, such as trailers, taxis, buses, and government-owned vehicles. The State of Illinois also issues special plates to members of the legislature, delivery vehicles, disabled veterans, motor vehicle dealers, and amateur radio operators. The Illinois disabled veterans license plates are a different color than the automobile plates and also carry the words "Disabled Veteran." Suggestions have been made that doctors and clergymen should also receive special plates so that they may be readily recognized.

Special licenses should be limited to those types which are absolutely necessary, because special plates are non-uniform, more costly to manufacture, and cause complex recording systems. Although it might be desirable to be able to recognize certain elements of the driving population readily, this identification can be better achieved by means of special insignia which can be placed elsewhere on the vehicle.

For example, it would appear advisable to cease the issuance of radio call letters to amateur radio operators. These call letters are composed of irregular combinations of letters and numbers which are usually difficult to read quickly and accurately and do not have good legibility distance. The value of the amateur radio operator in an emergency is well known. He could be identified by an additional plate or emblem carrying the words "Amateur Radio." This would identify the owner of the vehicle as an amateur radio operator and at the same time eliminate the confusing registration number.

# IV. THE DESIGN OF MOTOR VEHICLE LICENSE PLATES

Motor vehicle license plates must be designed so that they will accomplish their functions efficiently and economically. The items of information which are placed on the plate are the means of accomplishing these functions and are the primary design considerations.

The information that must be presented on license plates consists of: the vehicle registration number, the name of the state or province, and the year of issuance. Plates must be designed so that these three items are presented in such a manner as to be quickly and accurately perceived at a desirable distance. The general methods of presenting this required information have been developed in the last fifty years, but many variations are currently used and there is no agreement on the best method of presenting the required information.

Plate design items which must be studied are the composition and size of the vehicle registration number, the size of state name and year number, the effect of slogans and emblems, and color combinations. The plate size and shape, which would logically be determined on the basis of the decisions made with regard to the design items mentioned, has instead been standardized and become constant. Plate size and shape, therefore, becomes a controlling design factor.

Some miscellaneous factors that affect plate design are materials and paints, distribution methods, registration procedures, and various motor vehicle laws.

## A. STATE NAME AND YEAR NUMBER

With the increased use of state slogans or symbols on license plates, the space available for important information such as the state name and the year of issuance has been reduced considerably on the plates of many states. The preliminary report, "An Evaluation of the Purposes of Motor Vehicle License Plates,"[11] revealed that police officers, motor vehicle administrators, and other persons interested in license plate information feel that the state name and year number should be legible at one-half the distance that the vehicle registration number is legible. As mentioned in this report, "seventy-two percent of the law enforcement officers felt that it would be easier to identify the state if state slogans were removed and the size of the state name was increased."

Examples of states which have their names in small letters are: District of Columbia, $\frac{1}{2}$ in.; Illinois and Michigan, $\frac{9}{16}$ in.; Minnesota and Maryland, $\frac{5}{8}$ in.; and Arizona and Idaho, $\frac{11}{16}$ in. Two of the largest names are Iowa, $1\frac{1}{8}$ in., and Oklahoma, $1\frac{1}{16}$ in. With such variations in the height of state names and year numbers, as shown in Fig. 8, it was necessary to study character sizes to determine what height should be used to obtain the desired legibility.

### 1. Objectives

Studies of the legibility distance of state names and year numbers of various sizes were conducted to determine the effect of character size on the legibility distance of the state name and year number, the correct range of character sizes for use in state names and year numbers on license plates, the effect of abbreviations on the legibility distance of the state name and year number, and the effects of slogans on the legibility distance of the state name and year number.

### 2. Study Procedure

Test license plates were constructed with varying sizes of the state name and the year number. Some plates carried slogans, and some had abbreviations for the state name and the year number. Pure legibility tests were then conducted using the test plates.

Three groups of plates were prepared for the test and are shown in Fig. 9. Group A carried state names, year numbers, and slogans composed of letters 0.6 in. in height. Group B plates had state names and year numbers which were 1 in. high. Group C plates had state names and year numbers which were 1.5 in. high. The letters and numbers

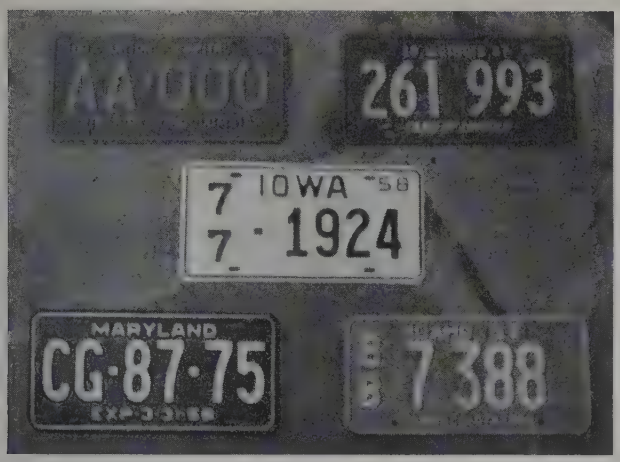



*Fig. 8. Variations in Height of Characters Used in State Names*

on all three groups were of the same style and had the same height-to-width ratio.

Plates in all three groups were 6 by 12 in. and had white characters on a dark blue background. All plates had a registration number consisting of six numerals, grouped three and three, with a space between the groups. The registration numbers were the Bureau of Public Road Series B numbers, 3 in. high and 1¼ in. wide, with ⅜-in. stroke. The numbers were spaced 1¾ in., center-to-center, except the third and fourth numbers, which were spaced 2¾ in., center-to-center. Table 12 shows the information which was presented on all test plates.

As indicated in Table 12, half of the plates in each group had full state names and half had abbreviations. Half of the year numbers on Group A plates were also abbreviated.

Table 12

Design of Test Plates for Study of State and Year Legibility

| Group | Registration No. | State | Year | Slogan |
|---|---|---|---|---|
| A | 937 624 | VERMONT | 1953 | LAND OF LINCOLN |
| (0.6 in.) | 882 105 | COLO | 1957 | THE BEEF STATE |
| | 952 303 | VIRGINIA | 1960 | LAND OF OPPORTUNITY |
| | 545 500 | MONT | 52 | AMERICA'S DAIRYLAND |
| | 674 405 | MO | 56 | SPORTSMEN'S PARADISE |
| | 160 350 | OKLAHOMA | 63 | HEART OF DIXIE |
| | 269 381 | KENTUCKY | 62 | PEACH STATE |
| | 182 264 | INDIANA | 1962 | GRAND CANYON STATE |
| | 530 870 | WYOMING | 1957 | WATER WONDERLAND |
| | 324 287 | DELA | 64 | SUNSHINE STATE |
| B | 312 617 | TENN | 55 | |
| (1.0 in.) | 495 194 | TENNESSEE | 58 | |
| | 431 487 | MINN | 54 | |
| | 797 331 | N Y | 57 | |
| | 962 213 | MARYLAND | 54 | |
| | 743 528 | MINNESOTA | 55 | |
| | 221 154 | NEW YORK | 57 | |
| | 906 112 | NEVADA | 56 | |
| | 537 880 | NEV | 56 | |
| | 105 003 | MD | 58 | |
| C | 189 975 | MONT | 58 | |
| (1.5 in.) | 431 053 | WISCONSIN | 60 | |
| | 501 758 | GEORGIA | 63 | |
| | 131 174 | IND | 62 | |
| | 443 393 | ALABAMA | 54 | |
| | 374 410 | ALA | 56 | |
| | 807 232 | WIS | 58 | |
| | 970 826 | ILL | 60 | |
| | 485 901 | ARKANSAS | 57 | |
| | 388 767 | FLORIDA | 61 | |

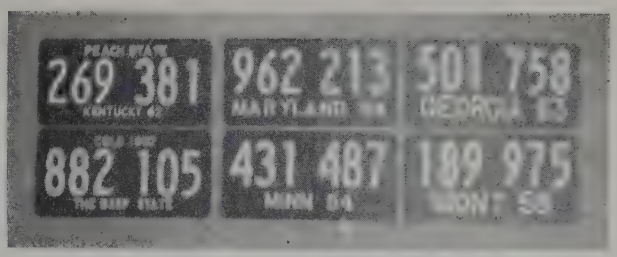



*Fig. 9. Test Plates Used in the State and Year Legibility Study*

The legibility tests were conducted in a large indoor area with artificial lighting. The plates were placed on a cart and advanced toward a single seated observer at a constant speed of approximately 1 ft per sec. A recorder, seated near the observer, recorded the distance at which the observer correctly identified the registration number, the state, the year, and in some cases the slogan.

The test plates from the three groups were distributed throughout the test, and the order of presentation was reversed for half of the observers. This was done to overcome effects of fatigue. The test was completed in about 65 minutes, with the observer having ample opportunity to rest his eyes following each reading while the cart was being returned to the starting position for placement of the next plate.

Ten observers viewed the test plates, and each observer read thirty plates, making a total of 300 observations.

## 3. Results

A summary of the observations of the test plates showing various state names and year numbers is presented in Table 13.

The values in Table 13 show the increases in the average legibility distances of the state names and year numbers which result with an increase in character size. Increasing the height of the characters from 0.6 in. to 1 in. increased the legibility distance of the state names by 102.5%. The increase in character size from 1 in. to 1.5 in. in-

Table 13

Legibility Distances of State Names and Year Numbers

| Plate Group | Legibility Distance (ft) | | | |
|---|---|---|---|---|
| | Reg. No. | State | Year | Slogan |
| A (0.6 in.) | 115 | 36 | 35 | 39 |
| B (1.0 in.) | 119 | 73 | 66 | |
| C (1.5 in.) | 118 | 88 | 81 | |

Table 14

Results of "t" Tests with State Name and Year Legibility Data

| Section | Groups Compared | Average Legibility Distance | Difference | "t" Value | Means Differ Significantly | Confidence Level |
|---|---|---|---|---|---|---|
| 1 | A<br>B | 36 ft.<br>73 ft. | 37 ft. | 25.0 | Yes | .01 |
| (State Names) | B<br>C | 73 ft.<br>88 ft. | 15 ft. | 6.6 | Yes | .01 |
| 2 | A<br>B | 35 ft.<br>66 ft. | 29 ft. | 17.4 | Yes | .01 |
| (Year Number) | B<br>C | 66 ft.<br>81 ft. | 15 ft. | 6.9 | Yes | .01 |

creased the legibility distance an additional 20.5%. These increases are significant at the 1% level according to the results of Student's "t" tests.

Similarly, the average distance at which the year numbers were legible increased 88.6% when character height was increased from 0.6 in. to 1 in., and 22.8% when character height was increased from 1 in. to 1.5 in. These increases also were significant at the 1% level according to Student's "t" test (see Table 14).

Table 14 also presents the average legibility distance of the registration numbers. Basing the required legibility distance for the state and year at one-half the distance at which the registration numbers were read gives a distance of approximately 60 ft. Referring to the curves in Fig. 10, this corresponds to a character height of approximately 0.9 in.

The readings of the observers were compiled and averaged to give the values for abbreviations and full state names which are shown in Table 15.

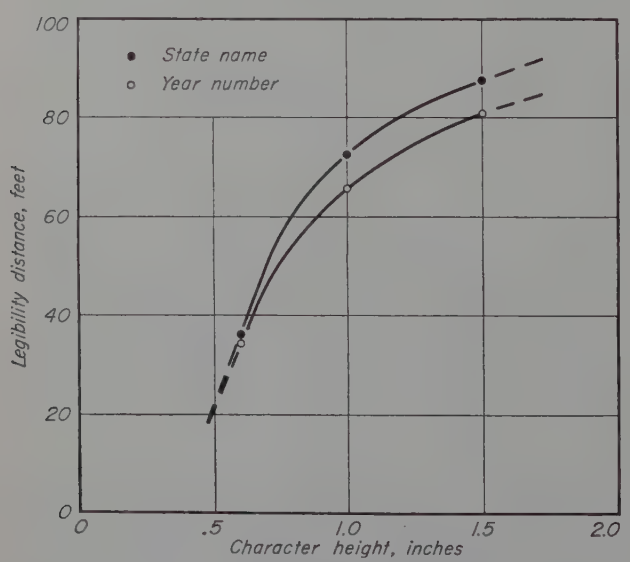



Fig. 10. Average Legibility Distances of State Names and Year Numbers

Table 15

Legibility Distances of State Names and Abbreviations

| Plate Group | Legibility Distance (ft) Full Name | Abbreviation |
|---|---|---|
| A (0.6 in.) | 36 | 36 |
| B (1.0 in.) | 77 | 69 |
| C (1.5 in.) | 86 | 89 |

These average values show that the abbreviations had little effect on the legibility distance of the state names. The data did show, however, that some state abbreviations could be read at a greater distance than the full name, and that other abbreviations could not be read as far as the full name.

The following state names are examples (all letters were 1 in. high):

| *State* | *Legibility Distance (ft)* *Full Name* | *Abbreviation* |
|---|---|---|
| MARYLAND (MD) | 80 | 54 |
| NEW YORK (N Y) | 76 | 86 |
| NEVADA (NEV) | 77 | 67 |

These figures indicate that the similarity of the shape of the state name or its abbreviation to other state names or abbreviations is important in determining the legibility of a state name or abbreviation. Some abbreviations are distinctive, but many are similar to others and responsible for confusion. For example, during the test, "MD" was frequently mistaken for "MO" and "IND."

Abbreviating the year number did not affect legibility according to the readings taken. The year numbers were given in full on five Group A plates, and abbreviated on five plates. The year numbers with the prefix (for example, *1957*) were read at an average distance of 35 ft, and the numbers without prefixes (for example, *57*) were also read at 35 ft. Therefore, dropping the prefix does not increase legibility. The prefix, of course, has no real value in year identification and may well be taken off the plate to improve the general appearance of the plate, especially if it is crowded.

## 4. Conclusions

The results of the state and year legibility distance tests form the basis for a number of conclusions:

a. The height of characters in the state name and year number should be approximately 1 in. if those two items are to be legible at the desirable distance of one-half the legibility distance of the identification legend.

b. State names and year numbers on most current plate designs are too small.

c. The effect of abbreviations on the legibility of the state name varies with different states.

d. Omitting the prefix *19* before the year does not affect the distance at which the year number is legible but will relieve the crowded appearance of many plates.

e. The State of Illinois should increase the size of the state name to at least 1 in.

## B. SLOGANS AND EMBLEMS

The placing of slogans, symbols, and emblems on license plates has become a popular practice in recent years. In 1959, twenty-eight states and seven Canadian provinces carried one or more of these designations.

Law enforcement officers and motor vehicle administrators were asked to give their opinion of slogans in the initial phase of this research project. Seventy-two percent of the law enforcement men and 83% of the motor vehicle administrators felt that it would be easier to identify the state if the state slogan was removed and the size of the state name increased. Eighty-five percent of the law enforcement officers and 89% of the motor vehicle administrators thought that removing slogans to make room for larger vehicle registration numbers would be desirable.

### 1. Effect on Legibility

A legibility study of various state names and year identifications is described in detail in the previous section of this report. Table 16 presents the results of these studies and illustrates the effect of removing slogans on legibility.

The figures in Table 16 show that removing slogans and using the increased space for larger state names and year numbers approximately doubles the distance at which these two important items of information can be read.

The harmful effect that slogans have on plate legibility substantiates the conclusion of the questionnaire respondents that "it would be easier to identify the state if the state slogan was removed and the size of the state name was increased."[11]

### 2. Conclusions

a. The presence of slogans and emblems on license plates reduces the space available for the state name and year number and thus reduces the legibility of the state name and year number.

b. The removal of slogans and emblems from license plates will permit the use of state names and year numbers large enough to be legible at the distance required for fast and accurate identification of the state and year.

Table 16

Effect of Slogans on Legibility of the State Name and Year Number

| Height of Characters (in.) | Legibility Distance (ft) | | |
|---|---|---|---|
| | State Name | Year Number | Slogan |
| 0.6 | 35 | 35 | 39 |
| 1.0 | 73 | 66 | .. |

c. The publicizing of a state by means of a slogan or emblem may have intangible value to the state but should be effected by means other than license plates.

## C. COLOR COMBINATIONS

The color of license plates has become an important factor in plate identification. Color aids in identifying the state or province in which a vehicle is registered and in most states is the primary method of identifying the year of issuance. In general, color combinations are chosen so that there is high contrast between legend and background (see Fig. 11). Occasionally, however, some states adopt a combination such as pink and white, or light blue and white, which reduces the contrast between legend and background and also reduces plate legibility.

Studies of the relative legibility of various color combinations are fairly numerous. A summary of the findings of these studies, together with reflectance values for various colors, should provide information which can be used to select suitable color combinations for license plates.

### 1. Previous Studies

A paper by Preston *et al.*[20] reported the results of studies with the following color combinations: black on white, green on white, blue on white, black on yellow, red on yellow, red on white, green on red, orange on black, orange on white, red on green, and black on purple. Their results showed that "combinations which rank high in legibility are those which have marked brightness contrast between print and background. Those of poor legibility have comparatively little brightness contrast between print and background. Blue on white, black on yellow, green on white, and black on white provide good legibility; green on red, red on yellow, and red on white provide fair legibility; and orange on white and red on green provide poor legibility."

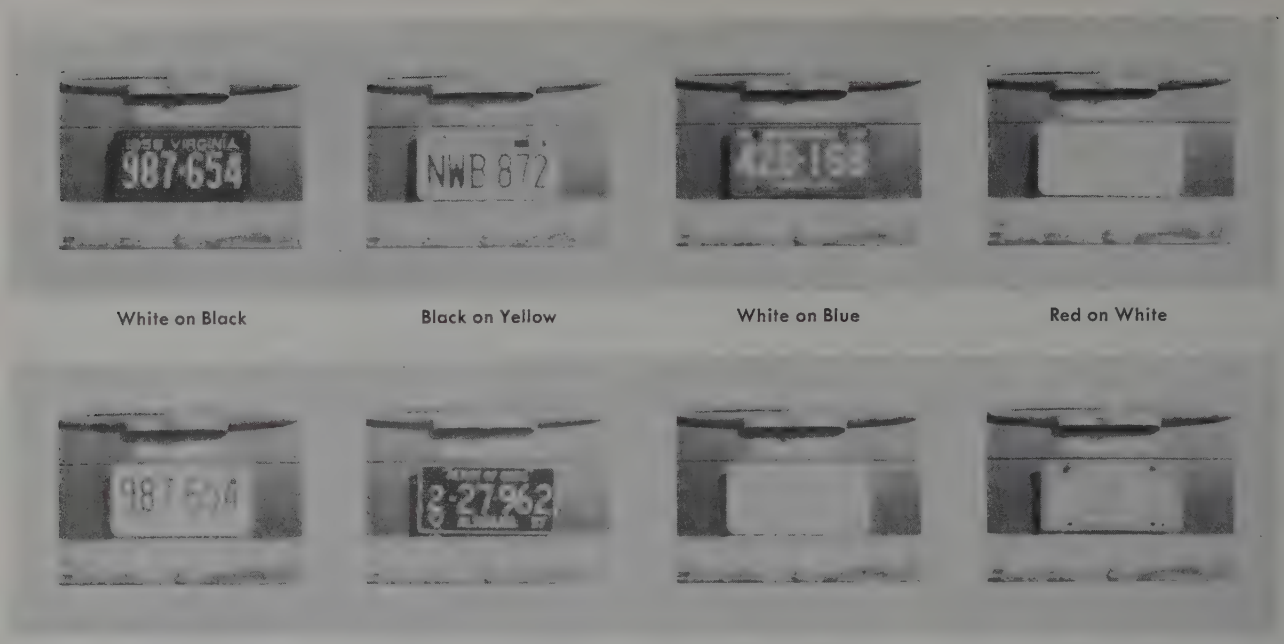



*Fig. 11. Color Combinations on License Plates*

Tests conducted by the Michigan Department of State in 1940[15] produced the following results:

| | *Legibility Distance (ft)* | |
|---|---|---|
| *Color Combinations* | *Day* | *Night* |
| White on Maroon | 158.4 | 114.0 |
| Maroon on White | 145.4 | 102.7 |
| Brown on Cream | 152.5 | 89.2 |
| Cream on Brown | 147.8 | 101.4 |
| White on Dark Green | 152.7 | 102.8 |
| Black on White | 146.9 | 107.1 |
| Dark Blue on Maize | 153.7 | 102.8 |
| Maize on Dark Blue | 142.3 | 110.5 |
| Dark Green on Light Green | 139.2 | 88.6 |

These values show that the dark green–light green combination did not provide enough contrast for good legibility. There were no important differences between all other combinations except that the brown–cream combination apparently had little contrast under artificial lighting.

Professor C. C. Wiley in his 1937 report *Automobile License Plates for Illinois*[27] stated:

a. For dark colors, use black and the darker shades of red, blue and green. Avoid the more brilliant shades.

b. For light colors use white, the more brilliant shades of yellow and light chrome orange, and perhaps the light tints of green and blue.

c. Avoid grays, browns, and other neutral shades. Do not put colors of similar reflecting power or wave length in combination. Thus, red on black is decidedly bad. Yellow on green is not good unless the green is very dark, etc.

d. Dark symbols on light backgrounds appear preferable to the reverse, but, with well chosen colors, the difference is not so marked as to be objectionable.

The Outdoor Advertising Association has prepared a brochure[16] which lists the strongest, most readable combinations for outdoor advertising. The ranking of color combinations is as follows:

1. Black on Yellow
2. Black on White
3. Yellow on Black
4. White on Black
5. Blue on White
6. White on Blue
7. Blue on Yellow
8. Yellow on Blue
9. Green on White
10. White on Green
11. Brown on White
12. White on Brown
13. Brown on Yellow
14. Yellow on Brown
15. Red on White
16. White on Red
17. Red on Yellow
18. Yellow on Red

This is one of the most comprehensive rankings available, and is an excellent guide for the choice of color combinations for license plates.

### 2. Reflectance Values

The General Electric Company[21] has prepared a brochure which gives the reflectance values for 48 different shades of paints. Table 17 lists the color reflectance values from this brochure. The reflectance values presented in this table can be used in choosing color combinations which have a high degree of contrast.

Dr. Lauer[14] has suggested that the differences

Table 17

**Reflectance Values for Different Shades of Paint**

| Color | Reflectance Values (%) |
|---|---|
| Black | 0 |
| Dark Blue | 8 |
| Dark Green | 8 |
| Dark Brown | 15 |
| Red | 22 |
| Orange | 36 |
| Light Blue | 40 |
| Light Green | 41 |
| Tan | 41 |
| Light Orange | 53 |
| Light Pink | 62 |
| Yellow | 66 |
| Ivory | 79 |
| White | 82 |

Source: General Electric Co.

between the reflectance values of colors used for legend and background should be no less than 45%. Following this recommendation, the following color combinations are suitable for use on license plates:

| *Color Combination* | *Percentage Difference Between Reflectance Values* |
|---|---|
| 1. Black and White | 82 |
| 2. Black and Ivory | 79 |
| 3. Dark Blue and White | 74 |
| 4. Dark Green and White | 74 |
| 5. Dark Blue and Ivory | 71 |
| 6. Dark Green and Ivory | 71 |
| 7. Dark Brown and White | 67 |
| 8. Black and Yellow | 66 |
| 9. Dark Brown and Ivory | 64 |
| 10. Black and Light Pink | 62 |
| 11. Red and White | 60 |
| 12. Dark Blue and Yellow | 58 |
| 13. Dark Green and Yellow | 58 |
| 14. Red and Ivory | 57 |
| 15. Dark Blue and Light Pink | 54 |
| 16. Dark Green and Light Pink | 54 |
| 17. Black and Light Orange | 53 |
| 18. Dark Brown and Yellow | 51 |
| 19. Dark Brown and Light Pink | 47 |
| 20. Orange and White | 46 |
| 21. Dark Blue and Light Orange | 45 |
| 22. Dark Green and Light Orange | 45 |

This listing can be used to select color combinations which are most suitable for use on license plates. Whenever possible, those combinations which rank high in contrast should be used.

### 3. Results of the University of Illinois Tests

The information obtained from previous studies and reports provides the information necessary for choosing color combinations which provide a high amount of contrast. Legibility studies were conducted to compare the legibility of dark legends on light backgrounds and light legends on dark backgrounds.

The test was conducted in a large indoor area. Plates were illuminated with low beams of a standard 12-volt headlamp system and were drawn toward the observer at a constant speed of 1 ft per sec. All plates carried four numbers, spaced 2½ in. center-to-center, 3 in. high 1¼ in. wide, with varying stroke width. The distance at which each of the four numbers was read correctly was recorded and averaged to give the legibility distance of the plate. Thirty observers were tested, and the following results were obtained:

| *Stroke Width (in.)* | *Legibility Distance (ft)* | |
|---|---|---|
| | *White on Blue* | *Blue on White* |
| 7/16 | 112.4 | 107.3 |
| 3/8 | 109.8 | 103.1 |
| 5/16 | 110.2 | 100.1 |
| 1/4 | 109.5 | 98.4 |

An analysis of this data showed that on the average, at this spacing, the light colored legends were 5.5% more legible than the dark on light. This is significant at the 1% level.

### 4. Color and State Identification

Seventeen states have adopted color combinations which they use every year, generally reversing the colors of the legend and background from year to year. This plan has two advantages: (1) after a satisfactory combination has been selected, there is assurance that plates will always have a color combination which provides good legibility, and (2) color becomes more important in state identification as police officers and the general public become familiar with the state colors.

States which adopt permanent color combinations must cooperate with nearby states to eliminate confusion which might result from the issuance of plates with the same legend and background colors. Vermont and New Hampshire, for example, both use green and white, but in years when Vermont uses a green background, New Hampshire uses white.

### 5. Conclusions

Legibility studies, reflectance values, and experience with colors provide information for the following conclusions concerning color combinations for license plates:

a. Color combinations used on license plates must have a high degree of contrast between legend

and background. This contrast must be maintained under both natural and artificial lighting.

b. The relative effectiveness of dark backgrounds as compared to light backgrounds is dependent upon conditions such as illumination, spacing, stroke width, and color. It is not possible to conclude that either light or dark backgrounds are preferable under all conditions.

c. Dark colors used on license plates should be black and the darker shades of blue, green, brown, and red.

d. Light colors used should be white, ivory, yellow, or light orange.

e. Grey, pink, light blue or green, and other neutral shades should not be used on license plates.

f. It would appear advantageous for states to adopt permanent color combinations, reversing the color of legend and background with each issue of plates.

g. The State of Illinois should investigate the feasibility of adopting one, two, or three color combinations which will provide a high degree of contrast between the legend and the background. These adopted combinations should then be alternated in succeeding years.

## D. OTHER FACTORS IN PLATE DESIGN

The design of motor vehicle license plates is affected by a number of factors which vary from state to state. In most states, motor vehicle laws or administrative procedures have required that additional items of information be placed on the plate, or that the plate be manufactured in a certain manner. The following sections present a general discussion of the advantages and disadvantages of certain practices.

### 1. Registration Procedures

The principal registration procedure affecting the design of license plates is the term of issuance of the plate. Some states use plates for two or more years, revalidating them by issuing small metal tabs or adhesive stickers. This procedure requires that the plate be designed so that the revalidating tabs or stickers can be applied readily.

The principal advantage of "permanent" plates is a saving in metal and manufacturing costs. In most states, however, extensive cross-reference files are required, and enforcement of the registration law becomes more difficult.

At the present time, the front mountings on most cars do not protect the plate from damage, and many front plates become badly damaged and illegible. The fact that some states have adopted and later abandoned a "permanent" plate indicates that a careful evaluation of the costs and benefits of such a plan must be made by a particular state before a decision can be made. Such an evaluation was beyond the scope of this investigation.

### 2. Area Identification

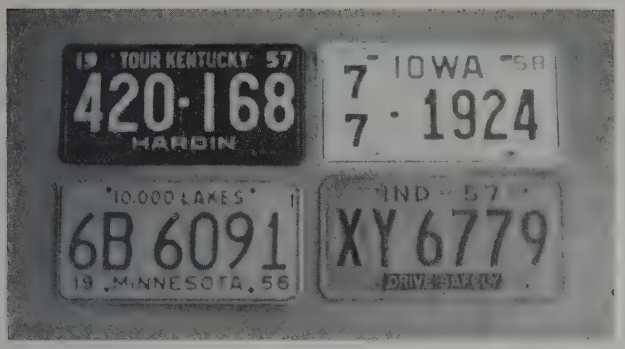
The value of county or area identification was studied in the first phase of this study.[11] On the basis of the replies and comments received in a questionnaire distribution, and in consideration of the many phases of license plate design, it was concluded that the designation of the vehicle owner's county or area of residence is not a true function of license plates. In cases where distribution is on a county or local level, county or area designation may help in the enforcement of registration laws. In cases where identification is difficult due to the type of numbering system in use, the number of vehicle registrations, and other design considerations, county or area designations may facilitate the accomplishment of the function of identifying the vehicle quickly and accurately.

As noted in the progress report,[11] the value of area identification is diminished by the presence of large metropolitan areas in the state, changes of address by vehicle owners, and the crowded condition of many plates which carry county names or code numbers. Various methods for showing an area identification are shown in Fig. 12.

In general, it would appear that county and area designations are feasible in states which do not have large concentrations of population and use an area distribution method. If the identification system is chosen so that it is easily perceived and has good legibility distance, county or area identification will have little additional value in identification of a particular vehicle. County or area identifications may be used, therefore, whenever they do not adversely affect the efficiency and economy of registration procedures.

### 3. Motor Vehicle Laws

State motor vehicle laws specify the requirements for displaying and mounting license plates. Generally, these laws state that plates shall be clearly visible, legible, kept free from dirt and foreign materials, and securely fastened. Most



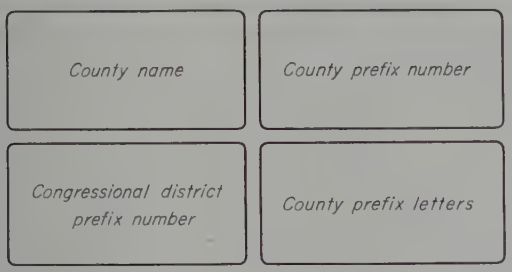




*Fig. 12. Methods of Designating County or Area*

states specify that plates must be mounted a certain distance above the ground.

Except for the mounting height, which must be observed by auto manufacturers in designing plate mountings, compliance with these sections which require that the plate be clean, in good condition, and clearly visible must be required of all vehicle owners if plates are to be legible (see Fig. 13). Also, those types of mounting frames which obscure part of the legend should be prohibited. Plastic or cellophane coverings which are designed to keep plates clean are often harmful in that they develop a cloudy appearance or reflect sunlight and cause the plate to become illegible. Law enforcement officers can help keep license plates legible by requiring motorists to keep plates clean and unobstructed.

### 4. Plate Materials

The materials used for license plates must be chosen on the basis of performance requirements and costs. Except for a few years during the war when metals were in short supply, plates have been made from steel or aluminum. Plastic and fiber materials were used during the war, but experience seems to have shown that steel or aluminum are well adapted to the manufacturing processes required for license plates.

Specific information regarding performance characteristics and costs of steel, aluminum, and other material are available from manufacturers

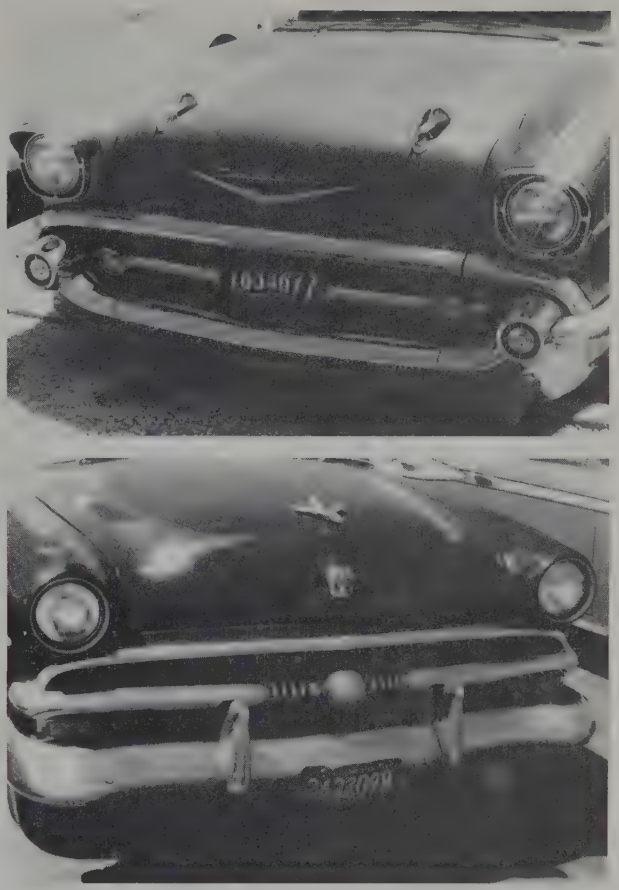


*Fig. 13. Examples of the Result of Improper Plate Mounting*

and metals research laboratories. An extensive treatment of the advantages and disadvantages of various materials is beyond the scope of this study. Whatever materials are used, the principal requirement is that they have sufficient durability so that the plate remains legible throughout the time that it is in use. Consequently, plates which are used for more than one year must be made from more durable material than plates used for only one year. Whenever plates are mounted so that they are protected from contact with other vehicles, the weight, thickness, and cost of plate materials can be reduced.

Paints used for license plates must be especially resistant to the effects of heat, rain, and road salts. Paint manufacturers are able to supply paints which have excellent resistance to the deteriorating effects of weather and chemical action which should be used on license plates.

## E. PLATE SIZE AND SHAPE

The size and shape of license plates have under-

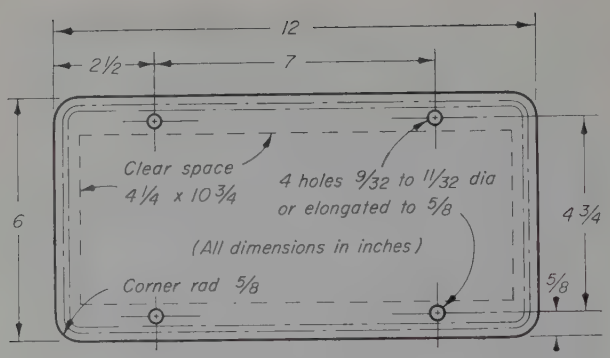



*Fig. 14. The Dimensions of the Standard License Plate*

gone many changes in the half century since plates first appeared on motor vehicles. Basically, the only requirement is that a plate have dimensions which permit the placement of all important information through the use of letters, numbers, or symbols which are large enough to be read at a desirable distance. The distance at which the plate should be legible is an arbitrary decision, and so the size of license plates has always been chosen on an arbitrary basis.

### 1. The Standard Plate Size

After more than twenty years of thought, discussion, and recommendations, the American Association of Motor Vehicle Administrators adopted a standard plate size of 6 by 12 in. in 1953. Fig. 14 illustrates the size, shape, and dimensions of the standard plate. The standard plate was favored by automobile manufacturers because it would enable them to provide simpler, stronger, and less expensive mountings, recesses in the automobile which would protect the plate from damage, and better illumination for the rear plate. The uniform size was also expected to be advantageous in the manufacture, storage, and distribution of plates.

The standard plate has given auto manufacturers an opportunity to provide better mounting, but many new cars do not provide suitable protection for the front plate, which often becomes badly damaged and illegible.

States which have reduced their plate size to conform with the standard are saving materials, but those which formerly had small plates now are using more materials than before. A certain amount of convenience and economy has resulted from making all plates the same size, however. The plates in Fig. 15 illustrate the variety of sizes and shapes used prior to adoption of the standard size.

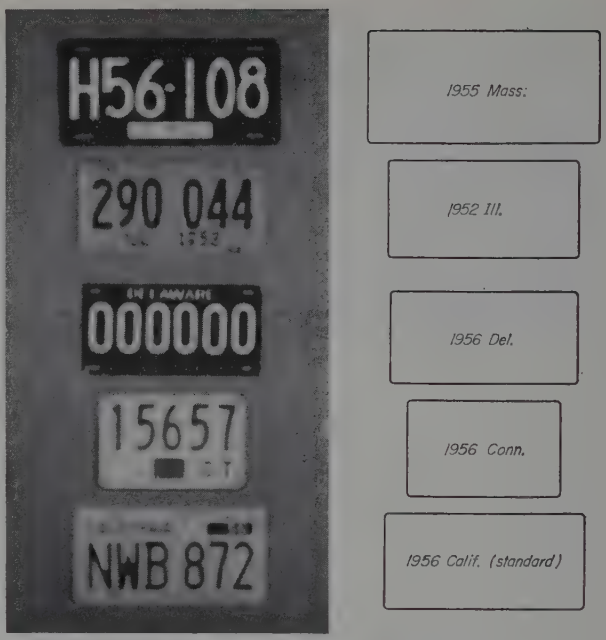



*Fig. 15. License Plate Sizes and Shapes in Use Before the Adoption of the Standard Plate Size*

The plate bearing the legend *NWB 872* has the standard dimensions, 6 by 12 in.

The most important effect of the standard plate is its effect on legibility. Prior to the adoption of the 6 by 12 in. plate, seventeen states (with more than 40% of the total automobile registration in the United States) used plates which were 12½ in. or more in length. Six other states issued some passenger plates which were 12½ in. or more in length. All these states were required to change their identification system, rearrange their plate content, or crowd the characters. In some cases, these forced changes were beneficial, but many states now have plates which are crowded in appearance, with characters spaced too closely for good legibility.

### 2. An Optimum Plate Size

Designing an optimum plate size requires decisions regarding the distance at which the vehicle identification number, the state name, and the year number should be legible.

The desired legibility distance of the registration number generally ranges from 100 to 150 ft. Previous legibility studies[1][3][12][15][17][27] have shown that this requires a 2½ to 3-in. high character. The state name should have a desirable legibility distance of 60 to 75 ft, which can be achieved with letters 1 in. high. The year number should have numerals of the same size as the state name and be legible at approximately the same distance.

Allowing ¾-in. margins above and below the characters and ½-in. spacing between the state and identification number, a total vertical dimension of 6 in. results.

The factors determining plate length are number of characters, width of characters, spacing between characters, and edge spacing.

In a previous section of this bulletin it was concluded that it is not desirable to have more than six characters in an identification number. According to previous legibility studies, the Bureau of Public Roads Series C alphabet has a daylight legibility distance of approximately 42 ft per in. of letter height.[17] A 3-in. letter or number, legible at approximately 125 ft, would have an average width of 1⅔ in. Grouping the characters in blocks of three, with ⅜-in. spacing between characters, a 1-in. space between groups, and ¾-in. end spacing results in a total license plate length of 14 in.

This plate size, 6 by 14 in., would permit the use of numbers with greater width and a more favorable height-to-width ratio, provide larger spaces between the numbers and letters in the identification numbers, and relieve the crowding which impairs the legibility and general appearance of many plates. Although a 14-in. plate is desirable, it does not appear likely that any changes will be made soon in the standard 6 by 12-in. plate. Now that a standard size has been adopted in the United States and Canada, it would be exceedingly difficult to make a change. If and when a change is made, it should be based on the required legibility of the items of information to be placed on the plate.

Additional research should be initiated to determine the functional and aesthetic value of reducing the length of the plate when the number of characters in the registration number is less than the desired maximum of six. This problem can be illustrated by trying to anticipate whether the legibility and appearance of a plate with less than five characters would be improved by reducing the 12-in. or 14-in. dimension of the plate proportionately.

### 3. Conclusions

a. A standard plate size has several advantages for the auto manufacturer and the motorist.

b. The present standard size of license plates, 6 by 12 in., does not permit sufficient character size and spacing to meet desired plate legibility.

c. Increasing the plate size to 6 by 14 in. would permit the use of characters with greater width and more favorable height-to-width ratio, permit larger spaces between characters, and improve the general appearance of many plates. These improvements would make plates legible at distances generally considered desirable.

d. Future changes in the size of the standard plate size should be based on the required legibility distances of the items of information placed on the plate.

e. Additional research should be initiated to determine the functional and aesthetic effect of reducing the length of the plate when the number of characters in the registration number is less than six.

f. The State of Illinois should continue to use the 6 by 12-in. standard size plate until such a time that a larger, more acceptable standard size can be adopted nationally.

# V. THE DESIGN OF REFLECTORIZED LICENSE PLATES

During the past few years, several states have adopted reflectorized motor vehicle license plates or reflectorized revalidation stickers primarily as an additional safety device in an effort to reduce nighttime traffic accidents. Of secondary concern was the effect on the legibility of the registration number at night.

## A. THE LEGIBILITY OF REFLECTORIZED PLATES

As was stated in an earlier section of this bulletin, the principal function of a motor vehicle license plate is to display the information necessary for fast and accurate identification of a vehicle under actual traffic conditions. The legibility of the information on the plate should then be the primary concern of plate designers. The added safety aspect of a reflectorized plate should be considered if it does not impair the plate's readability.

### 1. Purpose of the Study

The purpose of this study was to investigate and prescribe design criteria for a reflectorized license plate which will provide optimum legibility, both day and night, under actual traffic conditions. The use of a reflectorized license plate as a safety feature on a vehicle is discussed in this section where nighttime traffic accidents are analyzed for a state that has been using reflectorized plates for several years and has kept extensive accident records.

This phase of the license plate research project was intended to reveal the basic factors concerning the legibility of reflectorized license plates and to make evaluations of these components for an optimum plate design. With the data obtained in this study, it is hoped that license plate designers will be furnished with sufficient factual information to enable them to understand thoroughly the problems involved and to make justified decisions concerning the uses and benefits of reflectorized license plates.

### 2. Scope of the Study

Although this study is considered to be a comprehensive analysis of reflectorized motor vehicle license plates, several limitations were imposed on the project to avoid unnecessary complication of the subject material. Some of these limitations will become evident as the various sections of the study are discussed, but the principal limitations are stated below.

All of the experiments described herein deal with a relative legibility distance and not with a specific legibility distance. To determine the specific legibility distance of a license plate, the legibility test must be conducted under certain prescribed conditions with that particular plate. Specific legibility is an extremely complex quantity to determine because of all the variables encountered, both psychological and experimental. The results of the tests reported hereafter may be indicative of specific legibility distances but should not be considered as such. When the legibility distances of the plates are reported in this text, there is no inference that identical distances would be found under actual conditions. Relative differences in the various plate designs, however, are expected to be the same.

Throughout the study, only the legibility of the registration number under the various test conditions was determined. The legibility of the state name and year identification was assumed to follow the same pattern as this registration number; i.e., the best design for the registration number would also be the best design for the other information presented on the plate.

No studies were performed concerning the reflectorized revalidation stickers.

None of the results of these studies were confirmed under actual traffic or driving conditions. The laboratory testing apparatus for the specimen license plates was assumed to represent adequately the conditions which would be found under actual driving situations.

### 3. Test Conditions

Listed below are the variables which were considered in the study of the legibility of reflectorized license plates. The experiments detailed herein

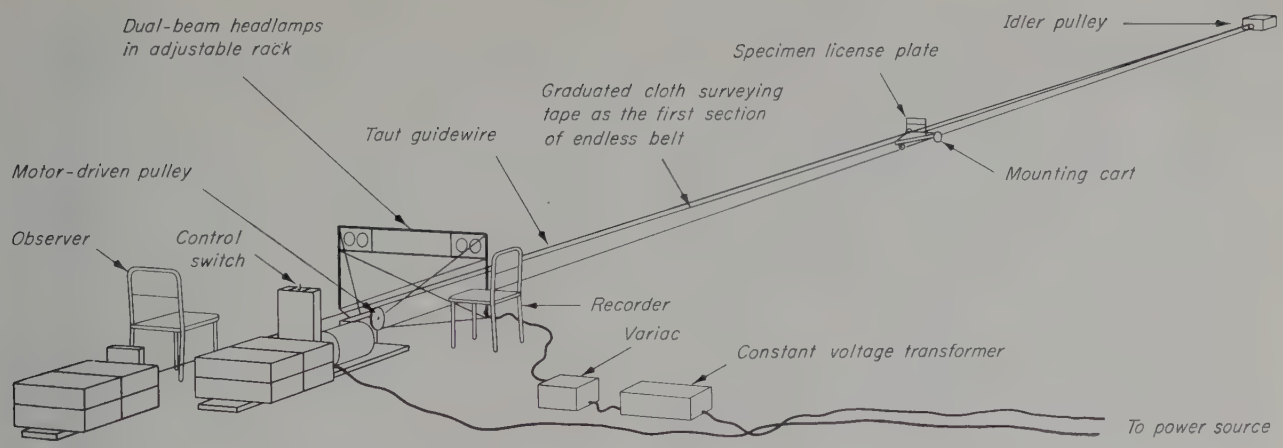



*Fig. 16. Sketch of the Test Apparatus*

were designed to examine the effects of all of these variables. Each variable was studied individually and its effect on legibility analyzed. Interactions of the variables were also considered.

a. Types of reflectorizing materials:
   - Flat sheeting (Type A).
   - Exposed lens sheeting (Type B).
   - Beads on paint (Type C).
   - Semi-gloss paint (Type D).
   - Aluminum paint (Type E).

b. Systems of reflectorization:
   - Background only reflectorized.
   - Legend only reflectorized.
   - Both background and legend reflectorized.

c. Stroke width of the characters.

d. Spacing of the characters.

e. Reflectorized borders.

f. Color combinations.

### a. Apparatus

Fig. 16 illustrates the mechanics of the legibility study apparatus. Essentially, the apparatus consisted of a special adjustable rack with two sealed-beam headlamp assemblies which simulated the headlamp system of an average automobile. The observer and the recorder were seated behind the headlamps as shown in the illustration.

Specimen license plates were brought toward the observer and returned to the initial position by an "endless chain" attached to a three-wheeled cart. The cart was powered by a gear-reduction motor controlled by the observer. The first 200 ft of the "endless chain" was a surveying tape graduated in feet and tenths of feet. As the tape ran over the motor pulley, the recorder could read directly the distance from the observer to the specimen plate.

*a. The specimen plate as seen by the observer.*

*b. The positions of the observer and the recorder behind the headlamp rack.*

*c. Mounting the specimen plates on the three-wheeled cart.*

*Fig. 17. Photographs of the Test Apparatus*

Figs. 17a, 17b, and 17c are photographs of the testing equipment. The only lights used during the tests other than the headlamps on low beam were two small 10-watt lamps, one on the recorder's

clipboard and the other to light the section of tape over the motor pulley.

b. Location

All of the legibility experiments were performed in the west great hall of the Memorial Stadium on the campus of the University of Illinois, Urbana, Illinois. The west great hall is 60 ft wide and 350 ft long, with very high ceilings and a dark brown vinyl tile floor. All windows were painted so that essentially no light could enter, permitting the experiments to be conducted in the daytime as well as at night. Adequate 110-volt power supply was available.

The test site was ideal from the standpoint that it was without extraneous light, day or night; was of adequate length and width; was level; was readily accessible; was heated for comfort; had controlled atmospheric conditions; had readily accessible power; and was without interference from traffic or onlookers. One minor disadvantage was that the type of floor surface could not be varied in the tests.

c. Specimen Plates

Ninety-seven different license plates of various designs were made for these studies. Because of the considerable expense and time involved in manufacturing the dies necessary for embossing and debossing the specimen plates, it was decided that flat plates with the copy silk-screened or a cut-out copy would be suitable.

All manufacturers of the various types of reflectorized materials were invited to participate in the production of the specimen plates to insure a quality product representative of their materials. The manufacturers were requested to make the plates in the laboratory at the University of Illinois under the supervision of the study personnel. They were also instructed to produce a license plate which would be representative of the quality that would be produced under mass-production procedures. Other than the silk-screened legend, which would ordinarily be roller-coated on an embossed or debossed plate, all other features on the plates are the same as production-run plates.

The actual designs of the specimen plates will be discussed in later sections of this bulletin when detailed information is given about each test. A summary of all plate designs and their specifications is presented in Appendix B. All plates were

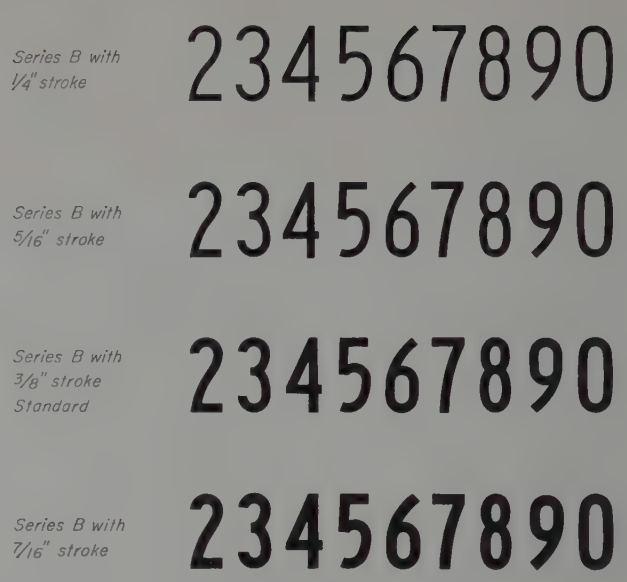



*Fig. 18. Style of the Numbers Used Throughout the Reflectorization Study*

given a code number and carefully stored in dust proof boxes before and during the tests.

All specimen plates used in these studies had four numbers as the copy or legend. Because the conduct of the test required the observer to read each number on the plate individually, more than four numbers would require too much time for each plate observation. The selection of only four numbers was decided by this time factor.

No letters were used on the plates because letters, in general, are less legible than numerals at a distance.[2] Any plate containing several letters would definitely be handicapped because of this difficulty.

The number *1* was omitted from all plates because of the unusual ease with which this number may be read. It appears to be legible at about twice the distance of the other numbers. Any plate containing the number *1* would have a definite advantage over another plate. The numbers used were *0, 2, 3, 4, 5, 6, 7, 8,* and *9.*

For uniformity throughout the test, all numbers were 3 in. high and were styled according to the U. S. Bureau of Public Roads Standard (and modified) Number Series B. The style of the numbers is shown in Fig. 18. Spacing and stroke width were varied according to the peculiarities of the test and are explained in the discussion of each test phase.

All plates were the standard 6 by 12-in. size with rounded corners. The legends on the plates were centered both horizontally and vertically.

The selection of the numbers for the legends of

the plates was performed in a carefully chosen manner. Because of the method used to compute the relative difficulty of each number's legibility, which is explained in detail in a later section, each number should occur on the specimen plates in the test the same number of times. Thus, in a particular test phase, the number 2 occurs in the legends approximately the same number of times as the other digits. If there are 64 license plates in the test and four digits on each plate, there are 256 total digits. As there are nine digits used (the number *1* was excluded), each digit should occur in the test 28 or 29 times (256/9).

As each digit should be represented 28 or 29 times in the test, a random selection of numbers would not give the desired results. Instead, another system of number selection was devised. After choosing the four digits on the first plate at random, the numbers to be placed on the second plate were obtained by subtracting *3* from each of the digits on the first plate. When the number *1* came up, it had to be discarded and the number *9* inserted. The next appearance of a *1* would be substituted with *8*, etc. This method of number selection for the legends of the plates makes each number appear approximately the same number of times in each location on the plate (outside left, center left, center right, and outside right).

d. Test Procedure

The conduct of the test was closely controlled. The observer was seated near the test apparatus for a period of about 10 to 20 minutes, a time which allowed his eyes to become adapted to the darkened conditions and also gave him a chance to relax and ask questions before the test. Once seated in the chair, he was given the instructions concerning the conduct of the test. He was told how to operate the motor, to be sure to rest his eyes between observations, that he was to read each individual number on the plate as soon as he was sure what it was, and that there were always four numbers on the plates, no letters, and that the number *1* would never appear on a plate.

After these detailed instructions were given to the observer, a specimen plate was snapped into the holder at the end of the test lane. The first plate was always started at the maximum distance of the apparatus and the remaining plates were then placed at a distance just beyond the observer's threshold of legibility.

Ample time was alloted for all observations, the average for each observer being 1¼ minutes per plate. The first series of 64 plates required about 1½ hours of the observer's time.

All of the specimen plates were coded and placed in the proper test sequence in special carrying cases. This precluded any mixup in the test. In case of a mixup, however, the recorder had all of the information concerning the plates written on the data sheet, affording a check on each observation.

As the cart carrying the test plate came forward at 1 ft per sec. and the observer began reading the numbers, the observer would indicate to the recorder what number he saw and where it was located on the plate, such as, "the third one is a four," or "the one on the right looks like a six." In case he made an error in reading a number, the recorder would tell him of his error by saying that "the third one is wrong," or "the middle two are wrong," etc. The recorder would not tell him of his mistake, however, until the cart had advanced about 15 ft after the reading. This gave him ample time to correct his mistake but not too long so that he might overlook it, assuming that he had it correct. If the reading was correct, the recorder would immediately read the distance on the tape and record it to the nearest foot on the data sheet. The specimen plate was brought forward until all numbers were read correctly. The observer would then reverse the motor and send the cart back to the assistant, who would place the next specimen license plate on the cart.

**4. Test Results**

This study of reflectorized license plates was performed in two series of tests. Series I tested 64 specimen license plates of specified designs. Series II required 35 specimen plates. Each test series was designed to determine the effects of certain variables encountered in reflectorized license plate design.

Reflectorized Test Series I was designed to study the effects of the following variables:

a. Stroke width of the characters.
b. Types of materials.
c. System of reflectorization:
   Legend only reflectorized.
   Background only reflectorized.
   Both background and legend reflectorized.
d. Contrast direction:
   Light legend and dark background.
   Dark legend on a light background.

Table 18. Corrected Average Legibility Distances for Series I Specimen License Plates

| Reflectorization System | Stroke Width (in.) | Reflectorized Plates: Average Legibility Distance (ft) — Flat Sheeting D/L | Flat Sheeting L/D | Exposed Lens Sheeting D/L | Exposed Lens Sheeting L/D | Beads on Paint D/L | Beads on Paint L/D | Painted Plates: Average Legibility Distance — Semi-Gloss Paint D/L | Semi-Gloss Paint L/D | Aluminum Paint D/L | Aluminum Paint L/D |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Background Only Reflectorized | 14/32 | 139.1 | ..... | 136.0 | ..... | 132.9 | ..... | 107.3 | 112.4 | 107.9 | 110.0 |
| | 12/32 | 135.1 | ..... | 134.4 | ..... | 134.5 | ..... | 103.1 | 109.8 | 106.6 | 114.7 |
| | 10/32 | 130.2 | ..... | 128.6 | ..... | 130.5 | ..... | 100.1 | 110.2 | 103.6 | 113.5 |
| | 8/32 | 127.2 | ..... | 128.4 | ..... | 126.3 | ..... | 98.4 | 109.5 | 103.5 | 110.2 |
| Legend Only Reflectorized | 14/32 | ..... | 147.7 | ..... | 141.6 | ..... | 144.4 | | | | |
| | 12/32 | ..... | 149.9 | ..... | 142.6 | ..... | 144.4 | | | | |
| | 10/32 | ..... | 150.6 | ..... | 147.4 | ..... | 145.6 | | | | |
| | 8/32 | ..... | 148.8 | 149.5 | ..... | ..... | 148.9 | | | | |
| Background and Legend Reflectorized | 14/32 | 140.2 | 140.8 | 135.0 | 139.7 | 138.8 | 140.8 | | | | |
| | 12/32 | 133.8 | 142.6 | 130.5 | 136.4 | 134.4 | 140.4 | | | | |
| | 10/32 | 134.0 | 141.5 | 131.1 | 143.1 | 129.4 | 141.0 | | | | |
| | 8/32 | 131.1 | 141.7 | 127.6 | 139.8 | 132.6 | 135.0 | | | | |

Key: D/L — Dark legend on light background.
L/D — Light legend on dark background.
..... Not a feasible combination.

Reflectorized Test Series II was concerned with the following variables and their influence on legibility:

a. Interaction between stroke width and the spacing of the digits.
b. Character spacing.
c. Use of borders.
d. Color combinations.

Both of the test series are discussed in detail in the sections which follow.

### Reflectorized Test Series I

As indicated in a study by Berger,[3] the stroke width of a luminous numeral is very important to its recognizability. The stroke width of a numeral may have possible interactions with these variables: (1) type of reflectorized material, (2) contrast direction, (3) the portion of plate reflectorized, and (4) the spacing of the digits. It is necessary, then, to study all of these variables to make an examination of possible interactions. The stroke width study was chosen to be the first of the investigations because the remaining studies depended upon the use of the proper stroke width of the characters in their design. Stroke widths at various spacings were studied in Series II.

Four stroke widths were tested in this study: 1/4, 5/16, 3/8, and 7/16- in. — corresponding to height-to-stroke width ratios of 12.0:1, 9.6:1, 8.0:1, and 6.8:1, respectively. These values cover the ranges in stroke widths currently used on license plates. Any stroke width less than 1/4 in. or greater than 7/16 in. would have detrimental effects on the daytime legibility of the characters. The style of the numbers remained constant for all plates, and the only dimension of the numbers that varied was the stroke width. Fig. 18 illustrates the style of the numbers and their stroke widths.

The spacing of the characters was maintained at 2½ in. center-to-center on all plates in Series I to prevent the introduction of an additional variable. Only two colors were used on all of the plates in this experiment, a dark blue and white. The use of a dark blue and white provided sufficient color contrast for good legibility. The maximum color contrast is, of course, a black and white, but black can not be reflectorized. Various color combinations were studied in Series II of this research.

Three systems of reflectorizing the plates were studied: (1) the background only reflectorized, (2) the legend only reflectorized, and (3) both the legend and the background reflectorized.

Five types of materials were represented on the specimen plates: (1) flat sheeting, (2) exposed lens sheeting, (3) beads on paint, (4) aluminum paint, and (5) semi-gloss paint. Aluminum paint was included in the study because Lauer[14] found that semi-reflectorized surfaces such as aluminum paint were beneficial under low illumination levels. All of the materials used on these specimen plates were those recommended by the manufacturers and were representative of the materials actually used for reflectorized license plates.

Thirty observers viewed each of the 64 specimen license plates. All observations were made using the low beams of the headlamps on the viewing apparatus.

Table 18 shows the corrected average legibility distances for each specimen license plate in Series I. Each cell on the chart represents one specimen license plate.

The calculations for the average corrected legibility distance were somewhat complex because they involved the determination of numeral difficulty correction factors. A numeral difficulty correction factor for each of the nine digits in each of the four positions on the license plates was calculated from the original data. The grand average legibility distance of all digits in all locations was divided by the average legibility distance (by

Table 19

Numerical Difficulty Correction Factors
Reflectorized Plates – Test Series I

| Number | Outside Left | Inside Left | Inside Right | Outside Right |
|---|---|---|---|---|
| 0 | 1.066 | 1.046 | 1.030 | 1.001 |
| 2 | 0.928 | 1.015 | 0.968 | 0.974 |
| 3 | 1.001 | 1.002 | 1.008 | 0.958 |
| 4 | 0.957 | 0.883 | 0.951 | 0.942 |
| 5 | 1.002 | 1.011 | 0.967 | 0.968 |
| 6 | 1.015 | 1.001 | 1.018 | 1.042 |
| 7 | 0.997 | 0.903 | 1.011 | 0.950 |
| 8 | 1.141 | 1.093 | 1.112 | 1.134 |
| 9 | 0.989 | 1.014 | 1.013 | 1.026 |

location) of the digit. The resulting number is the numeral difficulty correction factor.

Table 19 contains the numeral difficulty correction factors for the Series I reflectorized license plates.

These same correction factors were arbitrarily applied to the sixteen painted and aluminum plates. The sixteen nonreflectorized plates did not provide sufficient samples to determine a separate set of correction factors for these plates.

With these difficulty factors as arbitrary corrections, the average corrected legibility distance for each plate was readily calculated. The average of the thirty observations per digit per plate was multiplied by the proper correction factor. Because there were four digits on each plate, the average of these four corrected distances was the average corrected legibility distance for the plate in feet.

After the average corrected legibility distances were determined, the data were analyzed to determine the statistical significance of the differences. To do this, the reflectorized plates were analyzed separately from the nonreflectorized plates. An additional analysis then compared these two groups to determine whether the differences of the legibility distances of reflectorized and nonreflectorized plates were statistically significant.

To analyze this data by an analysis of variance, the two groups "background reflectorized" and "legend reflectorized" were combined to form a new group called "partially reflectorized." The elements and the results of the analysis of variance on the data for the reflectorized plates of Series I are shown in Table 20.

Similarly, with the nonreflectorized plates of Series I, an analysis of variance was performed in the usual manner.[5] The elements and the results of the analysis of variance tests on the semi-gloss and aluminum plates in Series I are shown in Table 21.

To test the significance of the differences between reflectorized and nonreflectorized plates, the

Table 20

Analysis of Variance — Reflectorized Plates — Test Series I

| Source of Variation | Sum of Squares | Degrees of Freedom | Mean Square | F Ratio |
|---|---|---|---|---|
| S | 83.48 | 1 | 83.48 | 18.39[a] |
| C | 1435.55 | 1 | 1435.55 | 316.20[a] |
| T | 63.86 | 2 | 31.93 | 7.03[b] |
| SW | 68.58 | 3 | 22.86 | 5.04[b] |
| S x C | 183.69 | 1 | 183.69 | 40.46[a] |
| S x T | 3.55 | 2 | 1.77 | 0.39 |
| S x SW | 14.71 | 3 | 4.90 | 1.08 |
| C x T | 4.44 | 2 | 2.22 | 0.49 |
| C x SW | 184.89 | 3 | 61.63 | 13.58[a] |
| T x SW | 23.07 | 6 | 3.84 | 0.85 |
| S x C x T | 14.44 | 2 | 7.22 | 1.59 |
| S x C x SW | 35.79 | 3 | 11.93 | 2.63 |
| S x T x SW | 18.81 | 6 | 3.13 | 0.69 |
| C x T x SW | 23.18 | 6 | 3.86 | 0.85 |
| S x C x T x SW | 27.26 | 6 | 4.54 | |
| Total | 2185.30 | 47 | | |

[a] Significant at the 1% level.
[b] Significant at the 5% level.

Key: S — System of reflectorization.
C — Contrast direction.
T — Type of material.
SW — Stroke width.

Table 21

Analysis of Variance — Nonreflectorized Plates — Test Series I

| Source of Variation | Sum of Squares | Degrees of Freedom | Mean Square | F Ratio |
|---|---|---|---|---|
| T | 23.04 | 1 | 23.04 | 13.32[a] |
| C | 223.50 | 1 | 223.50 | 129.19[b] |
| SW | 38.14 | 3 | 12.71 | 7.35 |
| T x C | 2.40 | 1 | 2.40 | 1.39 |
| T x SW | 15.38 | 3 | 5.13 | 2.96 |
| C x SW | 23.43 | 3 | 7.81 | 4.51 |
| T x C x SW (error) | 5.19 | 3 | 1.73 | |
| Total | 331.08 | 15 | | |

[a] Significant at the 5% level.
[b] Significant at the 1% level.

Key: S — System of reflectorization.
C — Contrast direction.
T — Type of material.
SW — Stroke width.

Student's "t" test was considered appropriate. Assuming the null hypothesis that the means are equal for painted plates and reflectorized plates, "t" was calculated to be 8.29 with 62 degrees of freedom.

$$"t" \ (0.99)\,(62df) = 2.66 < 8.28$$

The null hypothesis that the means are equal is rejected. The means are significantly different.

The differences in the legibility distances because of a change in the stroke widths of the characters were significant at the 5% level for the reflectorized license plates. Therefore, stroke width is an important determinant in legibility distance for reflectorized plates. For the nonreflectorized plates, however, a change in stroke width had no significant effects on the legibility distance in this test.

A wide range of stroke widths were tested ($\frac{7}{16}$, $\frac{3}{8}$, $\frac{5}{16}$, and $\frac{1}{4}$ in.). Stroke widths that are larger or smaller than those used in this test would probably affect the daytime appearance of the 3-in. characters. A highly significant $F$ ratio indicates that there is a distinct interaction between the

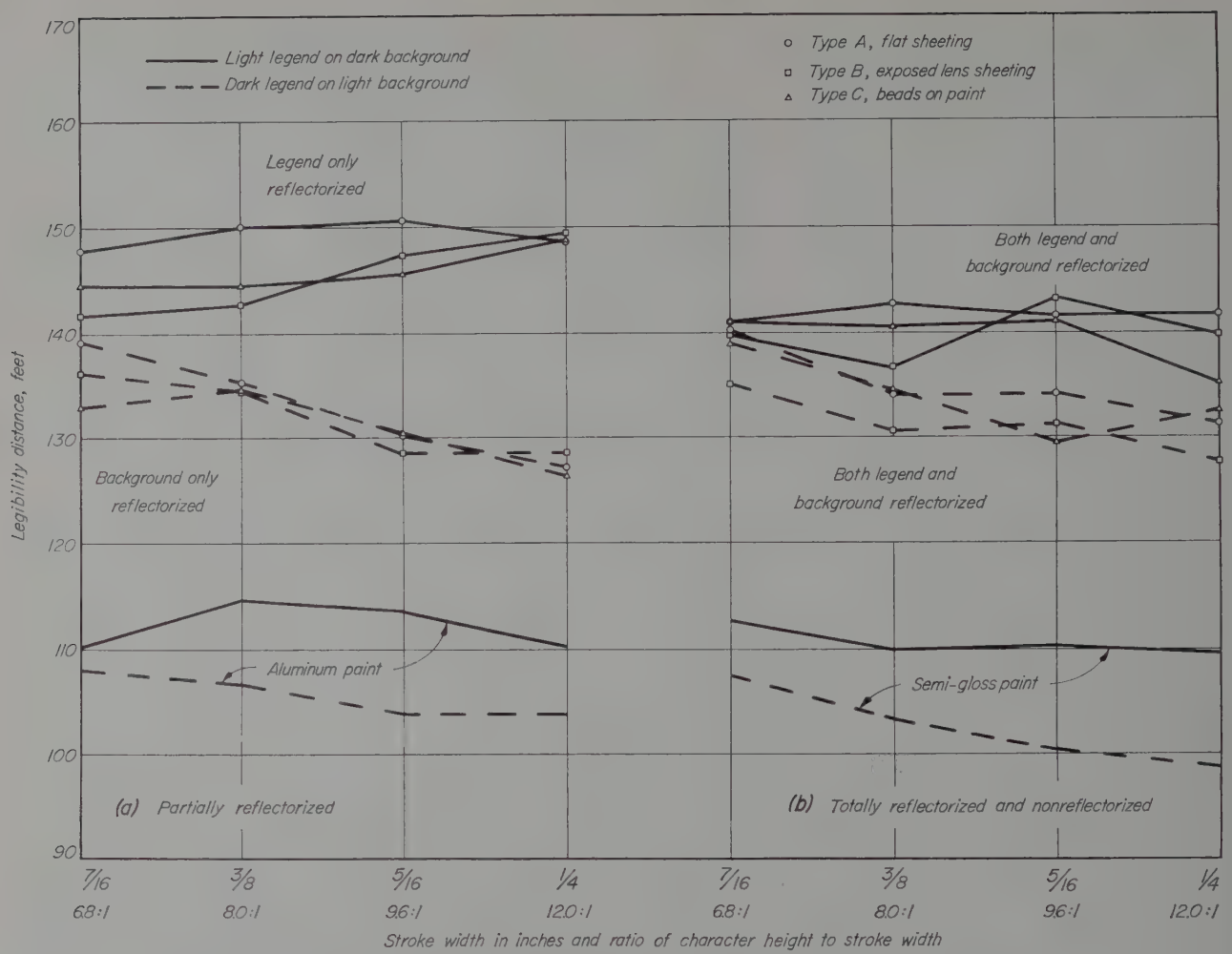


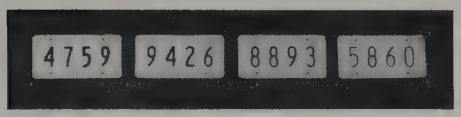

*Fig. 19. Effects of Stroke Width on Legibility Distance for Different Legends and Backgrounds*

thickness of the stroke and contrast direction. Thus, the optimum stroke width for the characters on a reflectorized license plate will be different for plates with a light legend on a dark background than for plates with a dark legend on a light background. There were no significant interactions between stroke width and any of the other main effects.

The relationship between stroke width and legibility distance for the various types of materials, the portion of the plate reflectorized, and the contrast direction is shown graphically in Fig. 19. Fig. 19a shows the data plotted for plates that were partially reflectorized and Fig. 19b shows the data for plates that were totally reflectorized or semi-gloss paint.

For dark legends on light backgrounds, the trend is the same for all types of materials and systems of reflectorization; i.e., the larger stroke widths are required to obtain the maximum legibility distance. For a dark reflectorized legend on a light reflectorized background, the $\frac{7}{16}$-in. stroke width gave the maximum legibility for all of the types of reflectorized materials tested. As detailed in a later section, this heavier stroke width is appropriate regardless of the spacing of the characters. For a dark nonreflectorized legend on a light reflectorized background, the same trend exists; i.e., a thicker stroke width is required for optimum legibility. The beads on paint materials appear to require a slightly smaller stroke width ($\frac{3}{8}$ in.) under these conditions. This variation may be attributed to experimental error, as the difference between $\frac{7}{16}$ and $\frac{3}{8}$-in. strokes for reflective material is very slight.

The use of an inappropriate stroke width of, say, $\frac{1}{4}$ in. for a dark legend on a light reflectorized background caused as much as a 10% decrease in legibility distance with this wide spacing of the digits.




*a. Plates with opaque legends on white reflectorized backgrounds with four different stroke widths. Left to right; 7/16, 3/8, 5/16, and 1/4 in.*

*b. Plates with white reflectorized legends on opaque backgrounds with four different stroke widths. Left to right; 7/16, 3/8, 5/16, and 1/4 in.*

*Fig. 20. Effects of Varying Stroke Widths on Reflectorized Plate Legibility*

With a light legend on a dark background, the situation is reversed and the smaller stroke widths are necessary for maximum legibility. When the legend only is reflectorized, a stroke width of ¼ in. is required regardless of the type of reflectorizing materials used. The use of the larger stroke width (7/16 in.) in this situation caused a decrease in legibility distance of about 5% (from 149.5 to 141.6 ft).

The effect of stroke width on the legibility distance when a light reflectorized legend is used on a dark reflectorized background does not seem so pronounced. There appears to be no definite trend of the curves for this situation. A stroke width in the middle range of values (5/16 or 3/8 in.) appears to give optimum legibility under these circumstances.

Although there were no statistically significant differences for semi-gloss painted plates and aluminum painted plates in character stroke widths, the trend seems to be the same as for reflectorized plates. Dark legends on light backgrounds require a heavy stroke width. A thinner stroke is appropriate for a light legend on a dark background.

The stroke width of the characters will also depend upon the brightness contrast of the color combination of the plate. The brightness contrast of the plates used in this study was nearly a maximum. If something other than a high brightness contrast is used for a license plate, adjustments of the stroke width are justified.

The results of the stroke width study agree with other similar studies.[2] [3]

The stroke width values reported are for 3-in. Bureau of Public Roads standard numbers. The use of a numeral of a different height or style would, of course, require some modification of the stroke width reported here. The height-to-stroke-width ratios should remain the same for any numerals which are suitable for license plates, however.

Figs. 20a and 20b are photographs showing the effects of varying the stroke widths on the plate

Table 22

**Results of Series I Legibility Studies Showing Only Plates of Optimum Stroke Width**

Reflectorized Plates — Average Legibility Distance (ft)

| | Flat Sheeting | | Exposed Lens Sheeting | | Beads on Paint | | Average | |
|---|---|---|---|---|---|---|---|---|
| | D/L | L/D | D/L | L/D | D/L | L/D | D/L | L/D |
| Background Only Reflectorized | 139.1 | ..... | 136.0 | ..... | 134.5 | ..... | 136.5 | ..... |
| Legend Only Reflectorized | ..... | 150.6 | ..... | 149.5 | ..... | 148.9 | ..... | 149.7 |
| Background and Legend Reflectorized | 140.2 | 142.6 | 135.0 | 143.1 | 138.8 | 141.0 | 138.0 | 142.2 |
| Average | 143.1 | | 140.9 | | 140.8 | | 141.6 | |

Painted Plates — Average Legibility Distance (ft)

| Semi-Gloss Paint | | Aluminum Paint | | Average | |
|---|---|---|---|---|---|
| D/L | L/D | D/L | L/D | D/L | L/D |
| 107.3 | 112.4 | 107.9 | 114.7 | 107.6 | 113.5 |
| Average | 109.8 | 111.3 | | 110.6 | |

Key: D/L — Dark legend on a light background.
L/D — Light legend on a dark background.
..... — Not a feasible combination.

legibility. This effect that stroke width has on legibility is explained through the phenomenon of "halation" or "irradiation."[2] [4] A bright object on a dark background appears to be wider than a similarly sized dark object on a bright background. This irradiation effect can be observed by comparing similar plates in Fig. 20.

The analysis of variance indicates that differences in legibility distance of the various types of reflectorized materials are statistically significant at the 5% level of confidence. Thus, the differences between the three types of reflectorized materials used in the study are significant, but not highly significant.

If a new table is constructed using only the best design of stroke width for each type of plate (plates with a maximum legibility distance), the difference between the types of materials becomes more evident. Table 22 presents this information.

On the average, the difference in legibility distance for the exposed lens sheeting and the beads on paint materials was negligible. The 0.1-ft difference is attributed to experimental error. The flat sheeting material, on the average, was 1.6% more legible than either the exposed lens sheeting or the beads on paint material. The differences between the various types of materials appear to follow

similar patterns with respect to either the portion of the plate reflectorized or the contrast direction. This was substantiated when no significant interactions between "type of material" and the other main effects were found in the analysis of variance.

Reflectorized plates, on the average, increased the legibility distance over painted plates by 28%.

$$\frac{(141.6 - 110.6)}{110.6} \times 100 = 28.0\%$$

This difference is highly significant statistically according to the results of the Student's "t" test.

Plates using an aluminum paint as the light color were, on the average, about 1.4% more legible than plates with a semi-gloss paint finish. This difference was statistically significant at the 5% level.

Although there appears to be no appreciable difference in the legibility of the types of materials used to reflectorize a license plate, other considerations have an important bearing on the choice of the reflectorizing material for a license plate. (See Additional Design Considerations, page 50.)

Three systems of reflectorization were studied in Series I of this research: the background only reflectorized, legend only reflectorized, and both the legend and the background reflectorized. It is well to remember that any portion of a license plate that is not reflectorized appears black at night. Even a white paint will appear black at the distance the plate becomes legible. Therefore, these plates were essentially black on white, white on black, a blue legend on a white background, and a white legend on a blue background.

Because the two groups, background only reflectorized and the legend only reflectorized, were combined for the analysis of variance and called "partially reflectorized," the statistical significance of these two combinations cannot be stated. The effects of a partially reflectorized plate as opposed to a totally reflectorized plate were analyzed statistically, however. The difference in legibility distance between these two groups was significant at the 1% level of confidence.

Table 22 gives some indication of the differences in legibility distance due to the various portions of a plate being reflectorized. At this large spacing of the digits (2½ in. center-to-center), the plates with the legend only reflectorized and the background opaque gave the maximum legibility distance, averaging 149.7 ft. Plates with both the background and the legend reflectorized were next with an average of either 138 or 142.2 ft, depending upon the contrast direction. The light legend on the dark background was the better combination. Lastly, the opaque legends on the reflectorized white backgrounds were legible at an average of 136.5 ft. Actually, however, this data is only valid for plates with extremely wide spacing between the characters on the plate. For smaller spacings, the difference in legibility distance for the systems of reflectorization is much less, and at extremely narrow spacings the situation reverses itself. The plates with reflectorized backgrounds then become more legible. The interaction of character spacing with the system of reflectorization is described in the discussion of Test Series II.

The term "contrast direction" refers to the use of a light legend on a dark background or a dark legend on a light background. In this section the term only has meaning when both the legend and the background are reflectorized or are both nonreflectorized on a specimen plate. On a partially reflectorized plate where, say, only the legend is reflectorized, it obviously must be a light on dark combination.

In studying contrast direction, therefore, only the totally reflectorized plates were analyzed. For the wide spacing of characters (2½ in. center-to-center), the plates with the white reflectorized legend on a blue reflectorized background were, on the average, 3% more legible than the reversed situation.

$$\frac{(142.2 - 138.0)}{138.0} \times 100 = 3\%$$

Again, this difference is dependent upon the spacing of the characters on the plate. Smaller spacings would reduce this difference.

An analysis of the nonreflectorized plates indicates the same trend as was found with the reflectorized plates. At this spacing of the characters, the light colored legends on the darker backgrounds were, on the average, 5.5% more legible than the dark on the light.

$$\frac{(113.5 - 107.5)}{107.6} \times 100 = 5.5\%$$

This difference is significant at the 1% level.

Fig. 21 shows photographs of some of the specimen license plates used in Series I taken at three distances. All of the plates used are not shown. Only those of the correct stroke width are pictured. The legibility distance for each of these plates is

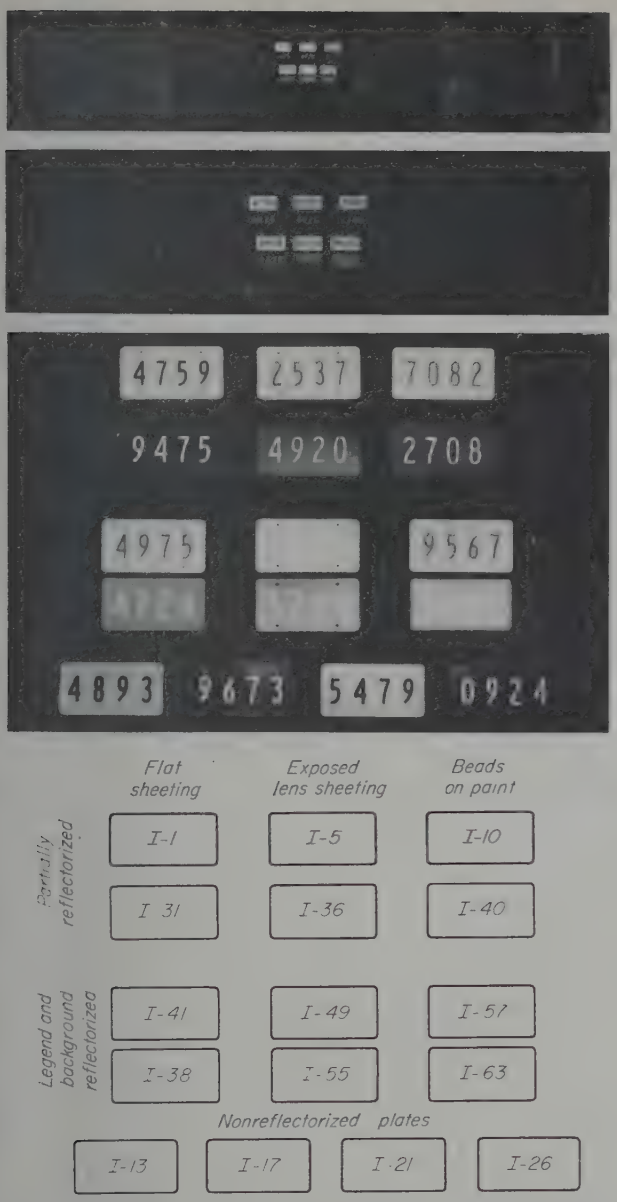



*Fig. 21. Specimen Plates from Test Series I with the Optimum Stroke Width of the Digits. (Photographed with Panatomic-X Film.) Plates are identified by code number. Complete descriptions may be found in Appendix B.*

recorded in Table 22. The bottom row of plates in the photographs are the nonreflectorized plates. The reflectorized plates are still legible at distances where the painted plates become illegible.

### Reflectorized Test Series II

Thirty-four specimen license plates were required in this test series. The details of the designs of these plates are noted when each variable is discussed. Twenty-eight observers read these specimen plates with the same testing apparatus shown

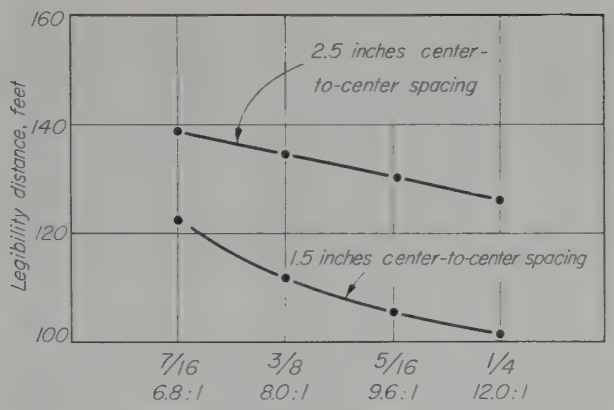



*Fig. 22. The Effect of Spacing on the Stroke Width of the Characters on Reflectorized License Plates*

in Figs. 16 to 17c. Low beams of the headlamps were used throughout this study. All legibility distances were calculated by the same procedure used in Series I, with the same numeral difficulty correction factors.

To determine any effects a closer horizontal spacing of the digits may have on their stroke width, four specimen plates were constructed with a spacing of 1½ in. center-to-center, tested, and compared with plates of similar design from Series I, where the spacing was 2½ in. These plates were made of flat sheeting with an opaque blue legend on a white reflectorized background. The four-number legend was centered on the plate.

If the horizontal spacing of the digits on the plate had no effect on their stroke width, the two curves in Fig. 22 would be parallel. At the wider spacing, the curve is a straight line, but when the spacing is reduced to a minimum, the plot assumes a new curved shape. This suggests that there is an interaction between stroke width and character spacing. One curve falls considerably below the other because of the effects of the reduced spacing.

Since the slopes of the two curves are in the same direction, the stroke width determinations found in Series I are still appropriate at the reduced spacing. The effects of stroke width appear to be more severe at a narrower spacing, as evidenced by the steeper slope of the curve for a small spacing. As horizontal spacing is decreased then, the effects of stroke width will become more significant. The use of an inappropriate stroke width at a narrow spacing has a greater effect on legibility than it would at a larger spacing.

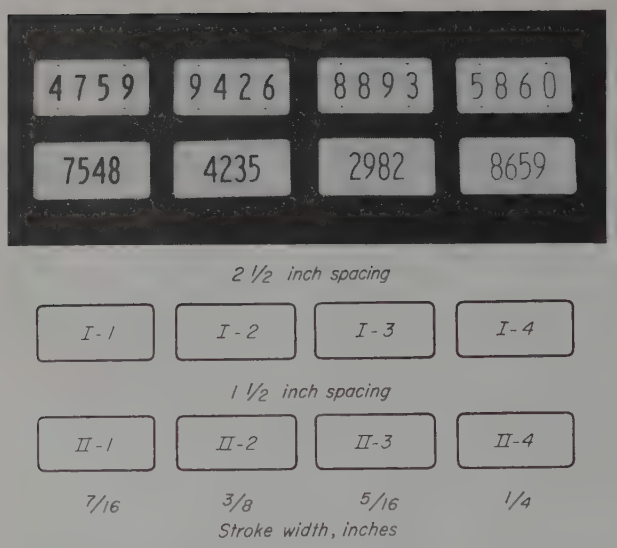



*Fig. 23. The Specimen Reflectorized Plates Used in the Study of the Effects of Spacing on the Stroke Width of the Characters*

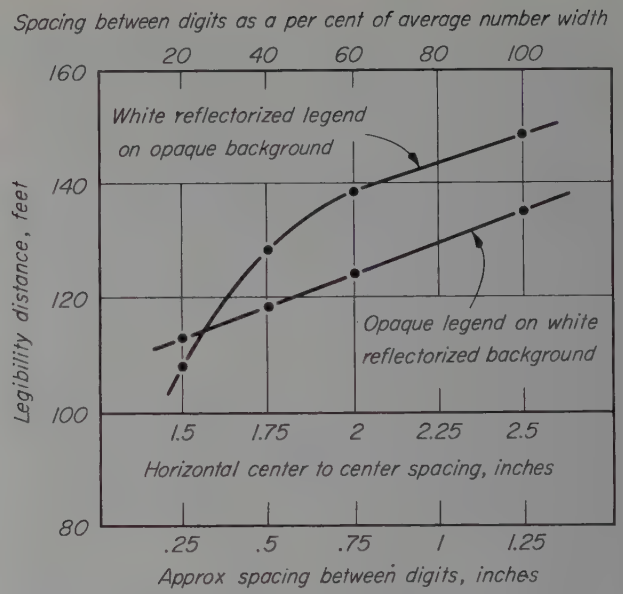



*Fig. 24. The Effects of Horizontal Spacing on the Legibility Distance of the Reflectorized Specimen Plates*

A photograph of the test specimens is shown in Fig 23.

To examine the effects of character spacing on legibility distance, six specimen plates were constructed and viewed by the 28 observers. Three of these plates had opaque blue legends on a white reflectorized background and three had white reflectorized legends on opaque blue backgrounds. Under each of these two conditions, three center-to-center spacings were represented: 1½, 1¾, and 2 in. The 2½ in. center-to-center spacings were represented by similar plates tested in the Series I study. The spacing between the digits in each case is approximately ¼, ½, ¾, and 1¼ in. The stroke width of the digits was ¼ in. for the white on blue plates and 7/16 in. for the opaque blue on white plates. The results are shown graphically in Fig. 24.

From an examination of Fig. 24 it is obvious that the spacing of the characters is a very important determinant in the legibility of a license plate. As these two curves are not similar in shape, the effects of spacing are different for plates of different contrast direction. For plates with an opaque legend on a white reflectorized background, the relationship between spacing and legibility distance is linear; i.e., an increase in spacing causes an equal increase in legibility distance. For the white reflectorized numerals on an opaque background, however, the relationship between spacing and legibility distance is definitely nonlinear in the smaller spacing range. Increases in spacing under these conditions cause disproportionate increases in legibility distance. At an optimum value for spacing (2 in.), the curves become parallel and linear.

Although fully reflectorized plates were not tested for their interaction with character spacing, it is assumed that their curves would fall somewhere between those shown on Fig. 24. The reflectorized white legend on the reflectorized blue background would have a shape similar to the upper curve but situated slightly below it. For plates with a reflectorized blue copy on a reflectorized white background, the curve would be similar to the lower curve but slightly above it.

The results of Test Series I, which were conducted with the maximum spacing of 2½ in., indicated that the light on dark contrast direction is more legible than the dark on light, which is again demonstrated in this test. But when spacing is decreased, the difference between the two becomes less until, at the minimum spacing of ¼ in. between digits, the reverse is true: the dark on light becomes more legible than the light on dark. (See Fig. 25.) Therefore, some knowledge of the character spacing is necessary before any decision can be made concerning the contrast direction. These conclusions are supported in another investigation.[4]

A possible explanation for the effects of the interaction between spacing and contrast direction is discussed by Case *et al.*,[4] through the phenomenon of irradiation. Case states:

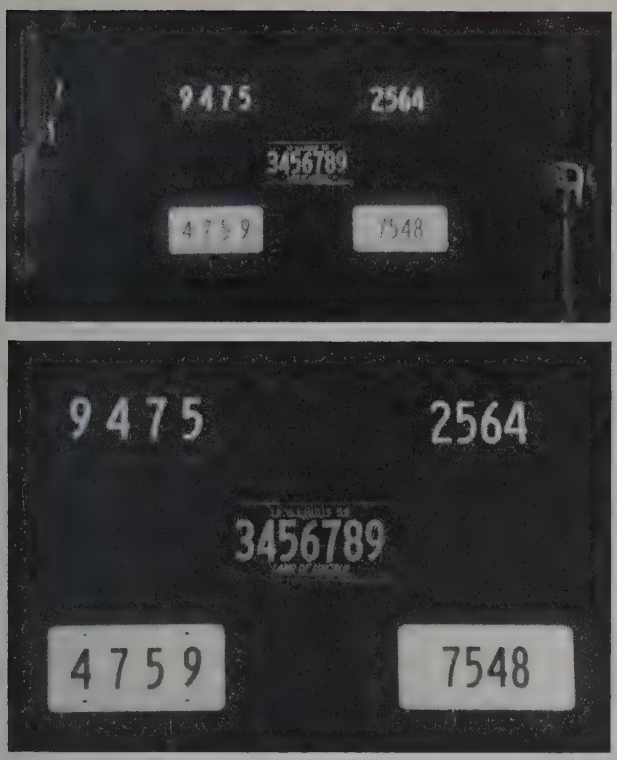



*Fig. 25. Comparisons of Reflectorized and Nonreflectorized Plates*

*Some reflectorized license plates from this study compared with the 1959 Illinois nonreflectorized license plate. The reflectorized plates are shown with two contrast directions and at two different spacings of the digits.*

The overall effect of this irradiation is an increase in the apparent stroke width of the white letters and therefore a decrease in the apparent spacing between letters. The stroke width of the black letters appears to either remain constant or actually decrease, thereby increasing the apparent spacing between the letters. . . . As spacing increases in magnitude, it eventually becomes so great that interletter interference does not occur, or at least it is not the limiting factor affecting the legibility.

The eight plates used in the spacing analysis are pictured at two distances in Fig. 26.

Two specimen license plates with borders were constructed and tested in Test Series II. The legibility distances of these two plates were compared with two specimen plates of similar design but without borders from Test Phase I. Twenty-eight observers also viewed these plates on the test apparatus with a low beam setting.

Table 23

Legibility Distances for Plates With and Without Borders

| | Average Corrected Legibility Distance (ft) | |
|---|---|---|
| Contrast Direction | With Border | Without Border |
| Background Only Reflectorized | 132.8 | 139.1 |
| Legend Only Reflectorized | 146.4 | 148.4 |

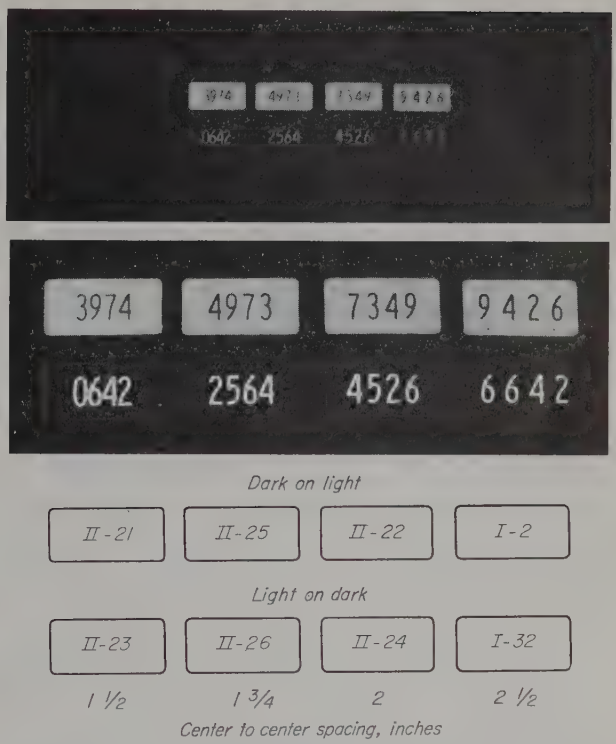



*Fig. 26. The Reflectorized Specimen Plates Used in the Study of Horizontal Character Spacing*

One plate had a $\frac{3}{16}$-in. opaque blue border placed $\frac{1}{4}$ in. from the edges of the plate. The background was reflectorized white. The second plate had a $\frac{1}{8}$-in. reflectorized white border and reflectorized numbers with an opaque background. Photographs of these plates are shown in Fig. 27. Table 23 gives the legibility distances for these specimen license plates.

A $\frac{3}{16}$-in. opaque border on a plate with a white reflectorized background had no significant effect on legibility distance. As is shown in the photographs of the specimen plates in Fig. 27, this type of border is just distinguishable even at moderate distances at night.

The legibility distance of an opaque plate with a white reflectorized legend and $\frac{1}{8}$-in. border was not significantly different from a similar plate with no border under these test conditions.

The results of this particular test may not be conclusive, as there were only two specimens tested. Perhaps a wider or narrower border may have significant effects on the legibility distance.

Twenty specimen license plates of various color combinations were viewed by the 28 observers in Test Series II. In addition to the standard procedure for viewing the specimen plates, the ob-

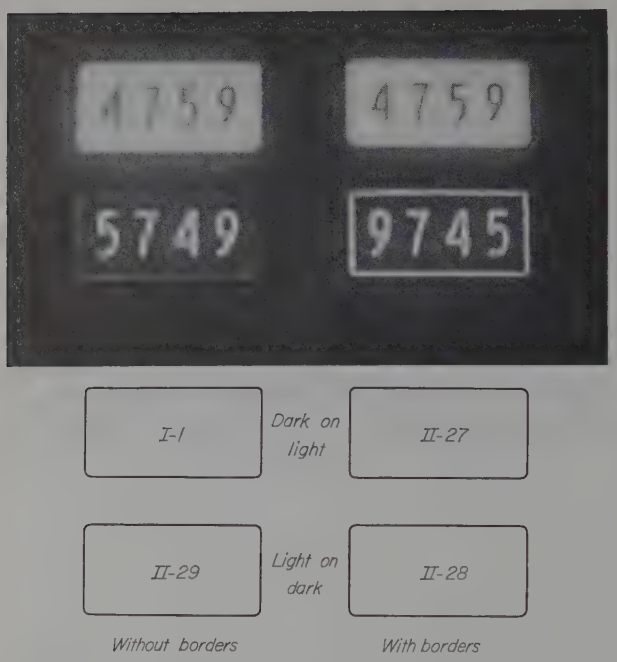



*Fig. 27. The Specimen Plates Used in the Study of Reflectorized and Nonreflectorized Plate Borders*

servers were also requested to identify the color of the legend and of the background as soon as the plates were placed on the mounting rack. These "apparent" colors were recorded on the data sheet along with the legibility distances. By this procedure, then, it is possible to determine if the reflectorized colors can accurately be identified at distances slightly beyond the legibility distance of the plate.

Table 24

Reflectance Values of Reflectorized Colors

| Color | Manufacturer's Serial Number | Reflectance Value Candlepower per "Normal" Footcandle per Plate |
|---|---|---|
| White | 3270 | 22.0 |
| Yellow | 3271 | 11.3 |
| Orange | 3274 | 9.8 |
| Green | 3277 | 7.6 |
| Red | 3272 | 5.8 |
| Blue | 3275 | 3.8 |
| Black (opaque) | ..... | 0.9 |

Flat sheeting colors were used in the test. It is assumed that reflectorized colors of other types of materials would exhibit the same effects on legibility. The colors used in the study and their reflectance values are presented in Table 24. The method of measuring the reflectance values for these colors is described in detail in Appendix A.

According to other studies, the legibility distance of a color combination depends upon many factors, the most important being the difference in reflectance values for the colors or, in other words, the brightness contrast between the legend and the background.

Table 25 is a description of the plates tested. The plates are arranged according to their relative legibility. Graphs of this data are shown in Fig. 28.

Table 26 gives the results of the color perception part of the study. This table contains data for both the legend colors and the background colors. The proportion of the observations that correctly defined the color of the background is considerably higher than those for the legend color. Averaging all of the colors, the color of the background was

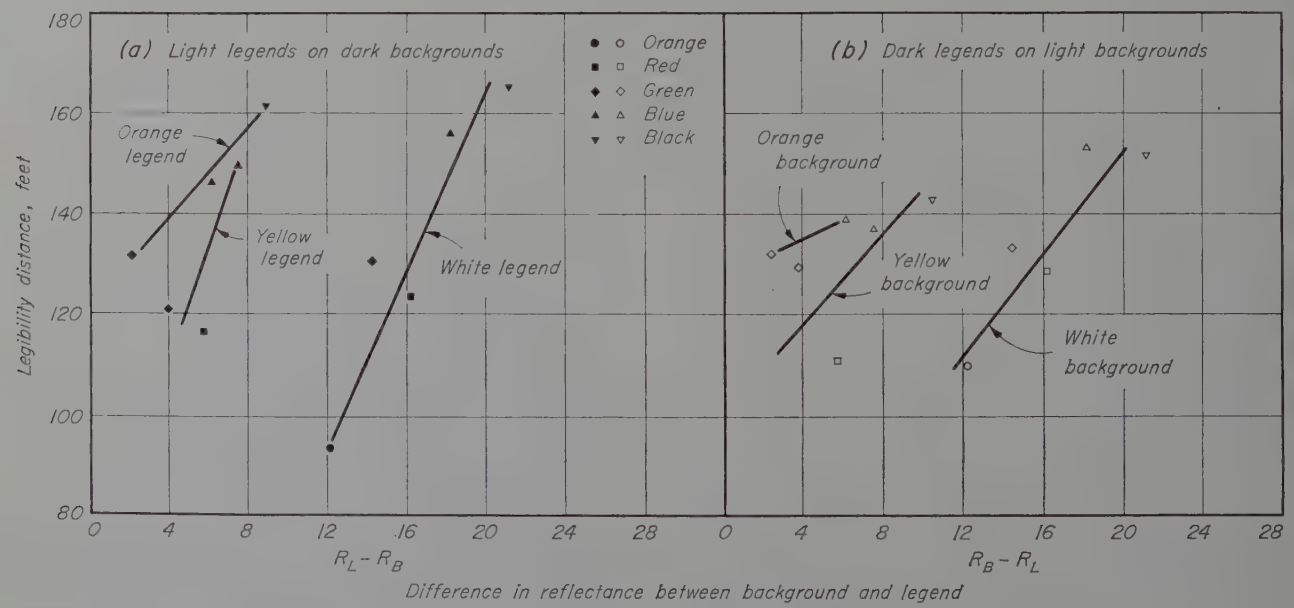



*Fig. 28. The Legibility of Various Color Combinations*

Table 25

Description of Plates for Testing Color Combinations

| Plate Code Number | Colors | Legibility Distance (ft) | $R_B - R_L$ or $R_L - R_B$ Difference in Reflectance Values |
|---|---|---|---|
| | Light Legends on Dark Backgrounds | | |
| 17 | White on orange | 93.0 | 12.2 |
| 13 | Yellow on red | 116.1 | 5.5 |
| 15 | Yellow on green | 121.8 | 3.7 |
| 16 | White on red | 124.2 | 16.2 |
| 18 | White on green | 130.9 | 14.4 |
| 20 | Orange on green | 132.0 | 2.2 |
| 19 | Orange on blue | 146.9 | 6.0 |
| 14 | Yellow on blue | 149.2 | 7.5 |
| 1–46 | White on blue | 155.8 | 18.2 |
| 35 | Orange on black | 161.8 | 8.9 |
| 1–31 | White on black | 164.6 | 21.1 |
| | Dark Legends on Light Backgrounds | | |
| 9 | Orange on white | 109.3 | 12.2 |
| 5 | Red on yellow | 110.7 | 5.5 |
| 8 | Red on white | 128.9 | 16.2 |
| 7 | Green on yellow | 129.5 | 3.7 |
| 12 | Green on orange | 132.7 | 2.2 |
| 10 | Green on white | 133.3 | 14.4 |
| 6 | Blue on yellow | 137.9 | 7.5 |
| 11 | Blue on orange | 139.6 | 6.0 |
| 36 | Black on yellow | 143.4 | 10.4 |
| 1–1 | Black on white | 152.0 | 21.1 |
| 1–41 | Blue on white | 153.2 | 18.2 |

Table 26

Color Identifications

| Color | Percentage Identified Correctly | Confused Mainly with |
|---|---|---|
| Legends | | |
| Black | 84.0 | .... |
| Blue | 16.4 | Black (54.5%) |
| Red | 63.0 | Black (13%), blue (6.5%) |
| Green | 27.0 | Black (32%), blue (18%) |
| Orange | 31.8 | White (40%), red (17%) |
| Yellow | 24.7 | White (65%) |
| White | 54.0 | Yellow (32%) |
| Average | 38.2 | |
| Backgrounds | | |
| Black | 87.0 | Red (12%) |
| Blue | 78.5 | Green (20%) |
| Red | 93.0 | Orange (7%) |
| Green | 98.8 | .... |
| Orange | 88.0 | Red (10%) |
| Yellow | 66.0 | Orange (24%), white (10%) |
| White | 94.0 | Yellow (4%) |
| Average | 85.5 | |

identified correctly 85.5% of the time and the legend only 38.2% of the time. Considerable variance of perception accuracy is noted between the various colors, however.

There appears to be a correlation between the legibility distance of a reflectorized license plate and the difference in reflectance of the colors used on the plate. The amount of the increase or decrease in legibility distance with various brightness contrasts appeared to vary with the particular colors studied.

In Fig. 28, linear relationships between legibility distance and brightness contrast are evident if all reflectorized white legends are grouped together. The same is true of yellow and orange legends. As the slopes of these three lines on the graph are not parallel, it would appear that other variables are involved in this relationship. The same general slope of the curves seems, however, to justify the conclusion that the higher the brightness contrast between the legend and the background, the better the legibility distance.

Examination of the curve for the reflectorized white legends and various background colors in Fig. 28 shows a considerable increase in legibility with an increase in brightness contrast. For example, a white legend on an opaque black background was 77% more legible than a white legend on an orange background.

Fig. 28 demonstrates the same general tendencies that were found with the light legends on dark backgrounds. There appears to be more scatter in the data, however, due possibly to the effects of irradiation. The proper stroke widths of the digits, as determined in Test Series I, were used on all of these plates.

The same conclusions are warranted for plates with a dark legend on a light background as were stated for the reversed situation: increases in brightness contrast between the legend and background will result in an increase in legibility distance of the plate; the amount of the increase (or decrease) varies with the particular colors used.

Comparisons between the two contrast directions are not warranted in this color combination study because of the large spacing (2½ in. center-to-center) between the digits. In general, however, at this spacing, the light legends on the dark backgrounds were more legible than the dark legends on the light backgrounds. This will vary, of course, with the spacing of the digits.

At this spacing, the effect of the brightness contrast on legibility distance appears to be more severe for plates with light legends on dark backgrounds than it is for the reversed situation. In other words, the slope of the curves for light legends on dark backgrounds is somewhat steeper than for dark legends on light backgrounds.

Considerable difficulty was experienced by the observers in attempting to determine the colors of the legends at distances slightly beyond the legibility distances of the digits. At this same distance, however, the colors of the backgrounds were readily perceived. This would indicate that the colors of the legends should not be used to identify the state or year of issuance of the license plates. The background color would be more suitable.

Photographs of some of the plates used in this color combination study are shown in Fig. 29. The effect of brightness contrast on legibility is clearly evident.

## B. ADDITIONAL DESIGN CONSIDERATIONS

Some elements of reflectorized license plate design which are not directly concerned with legibility are discussed below. All of these items must be considered in the design of a license plate if the plates are to serve their functions properly.

Most of the information presented below was taken from literature published in other studies. Complete reference is made to each source of information. These items are not discussed in any particular order or ranking of importance.

### 1. Visibility

The visibility of reflectorized license plates was studied by Larimer.[13] Some data were presented to establish typical visibility distances of unlighted vehicles, both with and without reflectorized license plates, relative to safe stopping distances. Visibility and performance limitations imposed by rain, mist, snow, and glare were considered in establishing the criteria. The observations indicate that a plate capable of reflecting five candlepower per incident foot-candle provides the minimum brilliance for requisite warning in typical situations.

The visibility of a reflectorized license plate is an important consideration under these conditions:

a. When a car is parked or stalled adjacent to a highway.
b. When approaching a "one-eyed" vehicle.
c. When a vehicle has faulty taillights.
d. When legibility is required of a license plate mounted on the front of the vehicle.

There is also some evidence that reflectorized license plates aid in nighttime distance perception if the plates are of a standard size.

Another consideration that cannot be neglected in the choice of materials for reflectorizing a license plate is the angularity of the material. The reflectorizing material should maintain an adequate percentage of its brightness at various angles of observation. It has been suggested that no less than two candlepower should be retained at a 30-degree entrance angle. The color of the reflectorized material should be essentially the same at night as in the daylight.

Additional information concerning the visibility of reflective materials (particularly highway signs) may be found in the literature.[10] [25]

### 2. Durability

Practical considerations require the reflective material and the metal backing to be durable throughout the vehicle registration period. Certainly, plates that are expected to last for a period of two to five years must be more durable than a plate that is issued annually.

The beads on paint-type reflective materials generally require a protective coating of some transparent material to insure their functioning

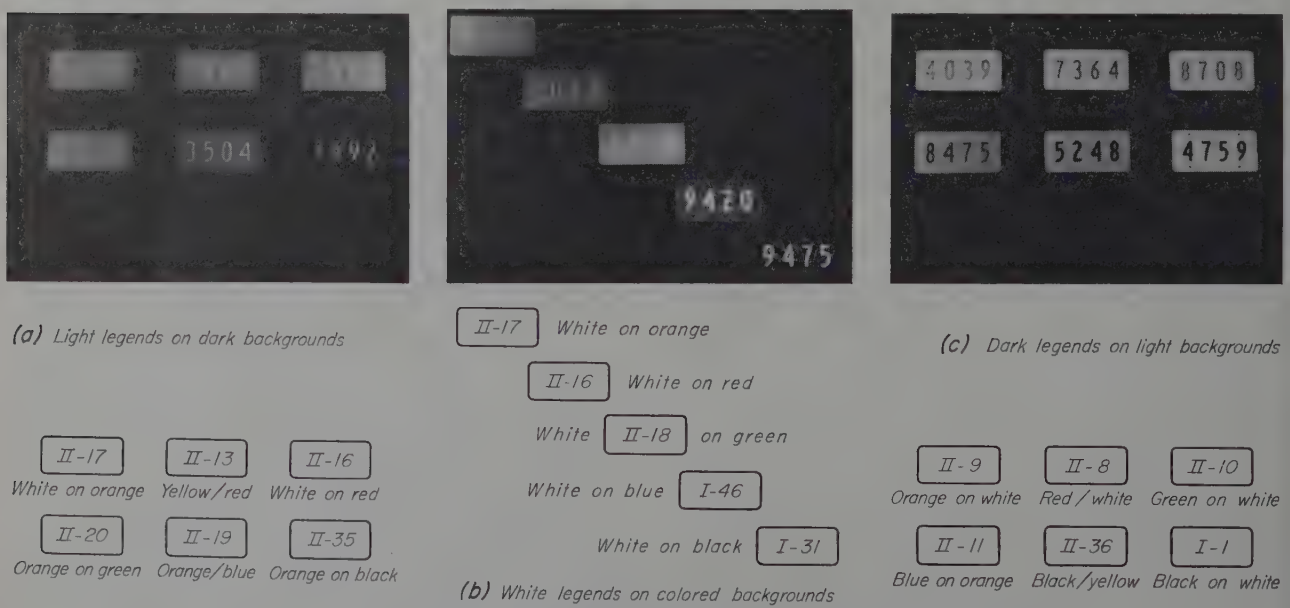



*Fig. 29. Some of the Specimen Plates Used in the Study of Various Color Combinations*
*Refer to Fig. 28 for a plot of the legibility distances for these plates. (Photographed with Panatomic-X Film)*

when the surface of the plate is wet. This coating must be sufficiently durable to perform adequately throughout the expected life of the license plate.

Because of careless plate mounting practices, license plate materials must be damage resistant and maintain their effectiveness though bent or mutilated. Havens and Peed[10] discuss the considerations of durability of reflective materials and propose methods of determining the resistance of various materials to weathering.

The choice of the type, thickness, and quality of the material for the license plate backing requires several considerations:

a. Cost.
b. Method of plate distribution.
c. Expected service life of the plate.
d. Availability of the materials.
e. Manufacturing restrictions.

#### 3. Ease of Cleaning

All reflective materials used on license plates must be kept reasonably clean so they may function properly. Practical considerations require reflective materials which may be simply cleaned with materials and methods normally used to clean automobile finishes.[13] Fundamental differences in the various types of reflective material make this requirement necessary.

#### 4. All-Weather Performance

Any reflective material which fails to function in adverse weather conditions is unsuitable for the reflectorization of a license plate. Specifications for reflective materials to be used on license plates should be required to maintain at least a minimum brightness when wet.

#### 5. Manufacturing Requirements

The choice of the design for a license plate must be such that it can be mass-produced quickly and easily without unnecessary complexities. Complicated production methods are generally not suitable for license plate manufacture.

#### 6. Cost

The most economical license plate that adequately serves all of the necessary functions as stated in the report will be the best design.

### C. THE EFFECT OF REFLECTORIZED PLATES ON ACCIDENT PREVENTION

During the past ten years, several states have adopted reflectorized plates in an effort to improve the visibility of license plate legends and to increase the distance at which plates are visible at night. The hope is that the increased visibility of plates will reduce the number of nighttime motor vehicle collisions. States which currently use plates with reflective legends or backgrounds are Delaware, Louisiana, Maine, Minnesota, North Dakota, South Dakota, and Wyoming. Minnesota adopted reflectorized plates in 1956, and as of the summer of 1959, it is the only state which has accumulated accident data to determine the effect of reflectorized plates on motor vehicle collisions.

During 1958, the Minnesota Department of Highways compiled motor vehicle collision statistics from 1955, the last full year that regular painted plates were used, and from 1957, the first full year that reflectorized plates were displayed on all vehicles. The report presented a directional analysis of all motor vehicle collisions in both rural and urban areas, at intersection and nonintersection locations, for both daylight and darkness. Accidents occurring during dawn and dusk and those involving out-of-state vehicles were not included in the analysis. The Minnesota report presented the 1955 and 1957 figures for the various accident types, and the percent of increase or decrease, but made no attempt to determine whether the increases or decreases were significant.

A statistical analysis of these Minnesota accident figures was made in this study to determine whether the increases or decreases in the figures for the various accident types were significant statistically. In addition, accident data from National Safety Council reports from all over the nation are presented for comparison with the Minnesota data.

#### 1. Method of Analysis

As a first step in determining the significance of increases or decreases in the Minnesota accident figures, the numerical difference between the 1955 and 1957 figures were computed for each type of accident and expressed as a percent of increase or decrease.

A statistical procedure was developed to determine if the 1955 and 1957 figures came from the same population. If the statistical analysis showed that the 1955 and 1957 figures did not come from the same population, then it was inferred that the increase or decrease from 1955 to 1957 was statistically significant at a level of 5, 10, or 20%. The analysis has been conducted on fatal and non-

fatal injury figures and on figures for the total number of accidents.

## 2. Results

Tables 27 to 31 present the accident figures which, according to the analysis, have increased or decreased significantly from 1955 to 1957. The figures are separated into two columns, "Day" and "Night." A confidence level is given, except where it was greater than 20%.

After consultation with statistical advisors, it was decided that those figures which changed significantly with 5 or 10% confidence should be considered conclusive. Table 27 indicates a significant increase in the total number of daytime motor vehicle collisions at rural nonintersection locations, and a significant nighttime decrease. Night collisions involving two vehicles moving in the same direction decreased significantly, as did collisions involving one vehicle leaving an alley or

Table 27

Rural Nonintersection Motor Vehicle Collisions

(All Accidents)

| Accident Type | Day | | | | Night | | | |
|---|---|---|---|---|---|---|---|---|
| | 1955 | 1957 | Percentage Change | Confidence Level | 1955 | 1957 | Percentage Change | Confidence Level |
| Going Opposite Direction — Both Moving | 830 | 778 | −6 | .20 | 435 | 388 | −11 | .10 |
| Going Same Direction — Both Moving | 636 | 681 | +8 | .20 | 362 | 324 | −10 | .10 |
| One Car Parked | 318 | 352 | +11 | .20 | 403 | 421 | +4 | ... |
| One Car Stopped in Traffic | 385 | 415 | +8 | ... | 97 | 121 | +25 | .20 |
| One Car Entering Alley or Driveway | 556 | 629 | +13 | .05 | 169 | 131 | −22 | .05 |
| One Car Leaving Alley or Driveway | 302 | 286 | −5 | ... | 77 | 54 | −30 | .10 |
| Total* | 3406 | 3582 | +5 | .05 | 1614 | 1518 | −6 | .10 |

* The figures for "Total" include all accident types, not just those listed in the table.

Table 28

Rural Intersection Motor Vehicle Collisions

(All Accidents)

| Accident Type | Day | | | | Night | | | |
|---|---|---|---|---|---|---|---|---|
| | 1955 | 1957 | Percentage Change | Confidence Level | 1955 | 1957 | Percentage Change | Confidence Level |
| From Same Direction — Both Going Straight | 56 | 73 | +30 | .10 | 21 | 9 | −52 | .10 |
| One Turning, One Straight | 494 | 629 | +27 | .05 | 154 | 150 | −3 | ... |
| One Stopped | 264 | 354 | +34 | .05 | 95 | 107 | +13 | ... |
| From Opposite Direction — Both Going Straight | 31 | 31 | .... | ... | 21 | 10 | −48 | .05 |
| One Left, One Straight | 166 | 228 | +37 | .05 | 71 | 68 | −3 | ... |
| Total* | 2745 | 3068 | +12 | .05 | 683 | 636 | −7 | .20 |

* The figures for "Total" include all accident types, not just those listed in the table.

Table 29

Urban Nonintersection Motor Vehicle Collisions

(All Accidents)

| Accident Type | Day | | | | Night | | | |
|---|---|---|---|---|---|---|---|---|
| | 1955 | 1957 | Percentage Change | Confidence Level | 1955 | 1957 | Percentage Change | Confidence Level |
| Going Opposite Direction — Both Moving | 558 | 501 | −10 | .10 | 383 | 291 | −23 | .05 |
| Going Same Direction — Both Moving | 816 | 1133 | +39 | .05 | 365 | 379 | +4 | ... |
| One Car Stopped in Traffic | 1001 | 1273 | +27 | .05 | 253 | 339 | +34 | .05 |
| One Car Parked | 1959 | 2158 | +10 | .05 | 2461 | 2670 | +9 | .05 |
| One Car Unparking | 983 | 1081 | +10 | .05 | 159 | 175 | +10 | .20 |
| One Car Entering Alley or Driveway | 705 | 857 | +22 | .05 | 228 | 214 | −6 | ... |
| One Car Leaving Alley or Driveway | 700 | 785 | +12 | .05 | 145 | 119 | −18 | .20 |
| Total* | 7050 | 8113 | +15 | .05 | 4091 | 4266 | +4 | .10 |

* The figures for "Total" include all accident types, not just those listed in the table.

Table 30

Urban Intersection Motor Vehicle Collisions

(All Accidents)

| Accident Type | Day | | | | Night | | | |
|---|---|---|---|---|---|---|---|---|
| | 1955 | 1957 | Percentage Change | Confidence Level | 1955 | 1957 | Percentage Change | Confidence Level |
| Entering at an Angle | 8187 | 8752 | +7 | .05 | 2608 | 2395 | −8 | .05 |
| From Same Direction — Both Going Straight | 448 | 521 | +16 | .05 | 181 | 157 | −13 | .20 |
| One Turning, One Straight | 1192 | 1620 | +36 | .05 | 470 | 589 | +25 | .05 |
| One Stopped | 3140 | 3980 | +27 | .05 | 1175 | 1290 | +10 | .05 |
| From Opposite Direction — Both Going Straight | 105 | 81 | +23 | .10 | 100 | 52 | −48 | .05 |
| One Left, One Straight | 1054 | 1549 | +47 | .05 | 676 | 722 | +7 | ... |
| Total* | 14,481 | 16,799 | +16 | .05 | 5327 | 5300 | −1 | ... |

* The figures for "Total" include all accident types, not just those listed in the table.

Table 31

Fatal and Non-Fatal Injury Accidents

| Accident Type | Day | | | | Night | | | |
|---|---|---|---|---|---|---|---|---|
| | 1955 | 1957 | Percentage Change | Confidence Level | 1955 | 1957 | Percentage Change | Confidence Level |
| Rural Nonintersection Motor Vehicle Collisions | | | | | | | | |
| Total* | 986 | 947 | −4 | ... | 564 | 503 | −11 | .10 |
| Rural Intersection Motor Vehicle Collisions | | | | | | | | |
| From Same Direction, One Turning, One Straight | 124 | 161 | +30 | .05 | 56 | 43 | −23 | .20 |
| One Stopped | 73 | 104 | +43 | .05 | 35 | 38 | +8 | ... |
| From Opposite Direction, One Left, One Straight | 62 | 101 | +63 | .05 | 35 | 29 | −17 | ... |
| Total* | 853 | 996 | +17 | .05 | 266 | 224 | −16 | .10 |
| Urban Nonintersection Motor Vehicle Collisions | | | | | | | | |
| Going Opposite Direction, Both Moving | 128 | 128 | .... | ... | 114 | 90 | −21 | .10 |
| Going Same Direction, Both Moving | 126 | 172 | +37 | .05 | 58 | 69 | +19 | ... |
| One Car Stopped in Traffic | 231 | 343 | +49 | .05 | 67 | 87 | +30 | .20 |
| One Car Entering Alley or Driveway | 92 | 139 | +51 | .05 | 45 | 40 | −9 | ... |
| Total* | 856 | 1081 | +39 | .05 | 623 | 650 | +4 | ... |
| Urban Intersection Motor Vehicle Collisions | | | | | | | | |
| Entering at an Angle | 1780 | 2110 | +23 | .05 | 630 | 626 | −1 | ... |
| From Same Direction, Both Going Straight | 58 | 76 | +31 | .10 | 33 | 26 | −21 | ... |
| One Turning, One Straight | 158 | 202 | +28 | .05 | 72 | 97 | +38 | .10 |
| One Stopped | 721 | 1079 | +48 | .05 | 312 | 382 | +22 | .05 |
| From Opposite Direction, One Left, One Straight | 204 | 336 | +65 | .05 | 153 | 185 | +21 | .10 |
| Total* | 2987 | 3742 | +25 | .05 | 1253 | 1340 | +7 | .10 |

* The figures for "Total" include all accident types, not just those listed in the table.

driveway. Collisions with vehicles parked or stopped in traffic increased in both daylight and darkness, however.

Table 28 shows a significant daytime increase in the number of collisions at rural intersections, and a slight, inconclusive nighttime decrease. Most of the night figures are too small for statistical significance, but the daytime figures show significant increases in several types of accidents.

Urban nonintersection accidents increased significantly during both daylight and darkness, according to Table 29. The daytime increase was, however, slightly larger and more conclusive. The number of collisions involving one car parked or stopped in traffic increased significantly in both daylight and darkness. Slight night decreases, compared with significant day increases, are noted where one car was entering or leaving an alley or driveway.

Table 30 shows a significant daytime increase in urban intersection motor vehicle collisions, and a slight nighttime decrease. Because urban intersection areas are generally lighted, it would be difficult to conclude that reflectorized plates are responsible for any improvements in accident experience.

The figures in Table 31 show that fatal and nonfatal injury accidents decreased significantly in rural areas in darkness. In daylight, there was a significant increase at rural intersections but a slight decrease at nonintersection locations. At urban intersections, fatal and nonfatal motor accidents increased significantly in both daylight and darkness, with the daylight increase being larger.

Table 32

Distribution of Accidents According to Time of Day

| Hours | Percent of Total Accidents | | | |
|---|---|---|---|---|
| | 1954 | 1955 | 1956 | 1957 |
| Midnight to 3:59 A.M. | 9 | 9 | 9 | 8 |
| 4:00 A.M. to 7:59 A.M. | 8 | 8 | 8 | 8 |
| 8:00 A.M. to 11:59 A.M. | 17 | 17 | 17 | 17 |
| 12 Noon to 3:59 P.M. | 22 | 22 | 22 | 23 |
| 4:00 P.M. to 7:59 P.M. | 28 | 28 | 29 | 29 |
| 8:00 P.M. to 11:59 P.M. | 16 | 16 | 15 | 15 |
| Total | 100 | 100 | 100 | 100 |

Source: National Safety Council, *Accident Facts*. Data from reports of 34 state traffic authorities.

At urban nonintersection locations, a significant daytime increase occurred in comparison to a slight nighttime increase.

### 3. Additional Information

Tables 32 and 33 present additional accident data which can be compared with the results of the statistical analysis of Minnesota accident figures.

Table 32 indicates that there has been little change in the percentage of day and night accidents during the four years that this information was accumulated. The ratio of day to night accidents appears to have remained nearly constant during the years 1954 to 1957.

In Minnesota, however, the percent of total accidents occurring in darkness has been decreasing since 1954. This is particularly interesting in view of the fact that total 1958 auto registrations in the state were 1,476,230, as compared with a registration of 1,306,491 in 1954. Table 33 presents the total number of day and night accidents in Minnesota from 1954 through 1958.

Information from the Minnesota State Safety Director indicates that no special nighttime safety

Table 33

Total Day and Night Accidents in Minnesota, 1954 to 1958

| Year | No. of Accidents | | Percent of Total | |
|---|---|---|---|---|
| | Daylight | Darkness | Daylight | Darkness |
| 1954 | 29,055 | 17,728 | 62.1 | 37.9 |
| 1955 | 33,107 | 18,904 | 63.7 | 36.3 |
| 1956 | 35,379 | 19,833 | 64.1 | 35.9 |
| 1957 | 37,840 | 19,644 | 65.8 | 34.2 |
| 1958 | 38,419 | 19,743 | 66.1 | 33.9 |

campaigns were carried on during any one particular year, but that there has been a continuous effort to warn the driving public of the hazards of nighttime driving. In particular, there was no important difference between nighttime safety promotions of 1955 and 1957.

## 4. Conclusions

Although much of the 1955 and 1957 Minnesota accident data available is insufficient for statistical analysis, it is possible to make the following conclusions regarding the effect of reflectorized license plates on accidents in Minnesota, and several others of a more general nature:

a. Reflectorized plates may have contributed to a significant reduction in the total number of night rural nonintersection motor vehicle collisions between 1955 and 1957 in Minnesota.

b. Reflectorized license plates may have contributed to a slight reduction in night rural intersection motor vehicle collisions between 1955 and 1957.

c. Daytime motor vehicle collisions at Minnesota rural intersection and nonintersection locations increased significantly from 1955 to 1957.

d. At urban nonintersection locations, both day and night motor vehicle collisions increased significantly, and it is not possible to conclude that reflectorized plates were of any benefit.

e. Reflectorized license plates cannot be assumed to have any effect at urban intersections, because such intersections are generally sufficiently lighted.

f. Additional data giving the number of day and night motor vehicle collisions should be collected by the various accident record agencies. This information is needed to determine the effect of efforts to minimize the number of nighttime accidents.

g. States which now use reflectorized plates should analyze their accident data and correlate motor vehicle collisions to time of day. This would provide additional information which can be analyzed statistically to determine more exactly the effects of reflectorized plates on motor vehicle collisions.

h. Additional accident data must be collected and additional studies conducted before the effects of reflectorized plates on motor vehicle collisions can be determined conclusively.

# VI. SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

The investigations described in this bulletin form the basis for a great number of conclusions and recommendations concerning the function and design of motor vehicle license plates. The conclusions and recommendations which are summarized in this section are divided into two categories: those which are general in nature and which apply to all states or provinces, and those which are intended specifically for the State of Illinois.

## A. GENERAL CONCLUSIONS

1. *The Functions of License Plates*

a. Motor vehicle license plates have two functions: (1) to identify the vehicle and (2) to show that the vehicle owner has complied with the motor vehicle registration laws.

b. The identification of the vehicle owner's county or area of residence is not a true function of license plates but may be helpful in enforcing registration laws and identifying vehicles, especially where the registration is on a county or regional basis.

c. The advertising and publicizing of the state by means of slogans or symbols is not a proper function of license plates.

d. To accomplish effectively the two main functions of license plates, each vehicle should be issued two plates, one to be displayed on the front and the other on the rear.

2. *The Design of License Plates*

a. A license plate registration system must be composed of combinations of characters which can be perceived quickly and accurately, are legible at a distance of approximately 125 ft under daylight conditions, and are readily adapted to filing and administrative procedures.

b. For fast accurate perception, the total number of characters in a registration system should be minimized. Six characters is a practical maximum.

c. Combinations of letters and numbers used as a registration system should have the letters grouped and separated from the numbers by a space, and the letters should always appear at the beginning (preferably) or at the end of the combination.

d. The total number of letters in any registration system using a combination of letters and numbers should not exceed two, unless the vehicle registration of the state exceeds the capacity of a two-letter, four-digit system.

e. The following registration numbering systems are easy to perceive quickly and accurately, can be designed to achieve desired legibility distances, and can be adapted to filing and administrative procedures:

(1) Straight numerical (*1* to *999 999*). This is the best system than can be used when the vehicle registration is less than one million.

(2) One letter, one to four digits (*A 1* to *Z 9999*). This can be used when the vehicle registration is less than 250,000.

(3) Two letters, one to three digits (*AA 1* to *ZZ 999*). This can be used when the vehicle registration is less than 600,000.

(4) Two letters, one to four digits (*AA 1* to *ZZ 9999*). This is best for use when vehicle registrations exceed one million but are less than six million.

f. Any of the registration numbering systems listed in conclusion *e* can be used for trucks and other special vehicles. In addition, the following systems are especially suitable for trucks or special vehicles:

(1) One to four digits, one letter (*1 A* to *9999 Z*).

(2) One to three digits, two letters (*1 AA* to *999 ZZ*).

(3) One digit, one letter, one to three digits (*1A 1* to *9Z 999*).

g. A registration numbering system composed of three letters and one to three digits (*AAA 1* to *ZZZ 999*) should not be used unless vehicle registrations exceed six million.

h. The numbers used in the vehicle registration number should be round or open in style, $2\frac{1}{2}$ to 3 in. high, $1\frac{1}{4}$ to $1\frac{3}{4}$ in. wide, and should have a stroke width of $\frac{5}{16}$ to $\frac{3}{8}$ in. The minimum values are for a 12-in. plate and the maximum values are for a 14-in. plate.

i. The letters used in the vehicle registration number should be round or open in style, 2¾ to 3½ in. high, 1⅜ in. to 2 in. wide, and should have a stroke width of 5/16 to 7/16 in. The minimum values are for a 12-in. plate and the maximum values are for a 14-in. plate.

j. For balanced legibility, the letters in a letter-number combination should be 5 to 10% larger than the numbers when one or two letters are used. When three letters must be used, the letters should be 20 to 25% larger than the numbers.

k. The state name and the year number should be legible at a distance approximately one-half that of the vehicle registration number, that is, at 65 to 70 ft.

l. The height of characters in the state name and the year number should be approximately 1 in. if these two items are to be legible at 65 to 70 ft.

m. State names and year numbers on most current plate designs are too small. The removal of slogans and emblems will permit the size of the state name and the year number to be increased so that they may be read at the distance required for fast and accurate identification of the state and year.

n. The publicizing of a state by means of a slogan or emblem may have an intangible value to the state, but should be effected by means other than license plates.

o. Color combinations used on license plates must have a high degree of contrast between legend and background. This contrast must be maintained under both natural and artificial lighting.

p. Dark colors used on license plates should be black and the darker shades of blue, green, brown, and red. Light colors should be white, ivory, yellow, or light orange. Neutral shades should not be used on license plates.

q. It appears advantageous for states to adopt permanent color combinations, reversing the color of legend and background with each issue of plates.

r. Additional research is needed to devise a vehicle registration system which lends itself to accurate transmission of license numbers over voice communication systems.

s. A standard plate size has several advantages for the auto manufacturer and the motorist and is desirable.

t. The present standard plate size, 6 by 12 in., does not permit sufficient character size and spacing to provide sufficient legibility at desired distances.

u. The standard plate size should be increased to a size which will permit the various items of license plate information to be legible at distances generally considered desirable. The size recommended is 6 by 14 in.

v. Additional research should be initiated to determine the possible value of reducing the length of the plate when the number of characters in the registration number is less than the desired maximum of six.

3. *Reflectorized License Plates*

a. Reflectorized license plates, on the average, increased the legibility distance over nonflectorized plates by 28%.

b. There appears to be no appreciable difference in legibility of the various types of materials used to reflectorize license plates. Considerations other than legibility have an important bearing on the choice of reflectorizing material used on a license plate.

c. The stroke width of characters is an important determinant of the legibility distance of a reflectorized license plate.

d. There is a significant interaction between stroke width and contrast direction.

e. Regardless of the type of material, character spacing, or the system of reflectorization, a wide stroke (7/16 in.) is required for maximum legibility distance when light copy is used on a dark background. In the conducted experiments, a thin stroke reduced legibility distance 10%.

f. With a light legend on a dark background, a thin stroke (¼ in.) is required for optimum legibility distance. The legibility distance was reduced by 5% in these tests when a thick stroke width was used.

g. There is a relationship between the stroke width of characters and their horizontal spacing. As the horizontal spacing is decreased, the use of an inappropriate stroke width causes a greater decrease in legibility distance than it would if the spacing were large.

h. The stroke width of characters should vary according to the color combinations used. If a color combination of moderate contrast is used, stroke widths in the middle range (5/16 to ⅜ in.) should be used.

i. Using a wide character spacing, light reflective legends on an opaque, dark background give the maximum legibility distance. A slight decrease in legibility distance was observed when both the

legend and background were reflectorized. Opaque legends on light reflective backgrounds were least legible at this wide character spacing.

j. Plates with white reflectorized legends on dark reflectorized backgrounds were 3% more legible than the reversed situation.

k. The horizontal spacing of the characters is an important determinant of the legibility distance of a reflectorized license plate. The effects of character spacing depend, however, upon contrast direction.

l. At a large digit spacing, the light on dark contrast direction is more legible, but when the spacing is decreased to a minimum (¼ in.), the dark legend on the light background becomes more legible.

m. There is a correlation between the legibility distance of a reflectorized plate and the brightness contrast of the colors used. The legibility distance increases as the brightness contrast increases.

n. Borders which were tested had no significant effects on legibility distance.

o. Important factors which must be considered in designing a reflectorized license plate are:

(1) Visibility characteristics of the material.
(2) Durability of the materials.
(3) Ease of cleaning.
(4) All-weather performance.
(5) Manufacturing requirements.
(6) Cost.

p. Reflectorized license plates may have contributed to a slight reduction in the total number of night rural nonintersection motor vehicle collisions between 1955 and 1957 in Minnesota.

q. Reflectorized plates may have contributed to a slight reduction in night rural intersection motor vehicle collisions between 1955 and 1957 in Minnesota.

r. Additional accident data is needed to determine more exactly the effects of reflectorized license plates on motor vehicle collisions.

## B. SPECIFIC CONCLUSIONS FOR THE STATE OF ILLINOIS

1. The State of Illinois should continue to use the present standard 6 by 12-in. size plate until a larger, more acceptable size of 6 by 14 in. can be adopted nationally.

2. The State of Illinois should augment its straight numerical registration numbering system with a system consisting of a combination of letters and numbers.

3. The registration numbering system recommended for adoption by the State of Illinois is the retention of all straight numerical combinations from *1* to *999 999*, together with the adoption of combinations of two letters and one to four digits. In this system, all letters except *I*, *O*, and *Q* are to be used in all combinations except those deemed objectionable. This system will permit the retention of 999,999 easily read and highly legible plates and will provide a total of approximately 6,250,000 combinations.

4. An alternate recommendation for the Illinois vehicle registration numbering system consists of two letters followed by one or four digits. All letters except *Q* are to be used in all combinations except those deemed objectionable. This system will provide approximately 6,200,000 uniform combinations.

5. The numbers used in the Illinois vehicle registration system should be modified Bureau of Public Roads Series B, 2¾ in. high, 1¼ in. wide, and should have a $\frac{5}{16}$-in. stroke width when placed on the 6 by 12-in. plate.

6. Letters used in the Illinois vehicle registration system should be modified Bureau of Public Roads Series B, 3 in. high, 1½ in. wide, and should have a ⅜-in. stroke width when placed on a 6 by 12-in. plate.

7. The registration numbering system used for Illinois truck plates should be revised so that the classification letter or letters appear at the end of the letter-number combination.

8. Special plates, such as for buses, taxis, and livery vehicles, should be issued with one letter, excluding *Q*, followed by one to four digits. The word *Bus*, *Taxi*, etc., may also be placed on the plate or certain letter series may be assigned to the various vehicle classes.

9. The practice of issuing call letters to amateur radio operators should be discontinued as soon as possible.

10. The practice of issuing special license plates to disabled veterans should be discontinued as soon as possible.

11. The State of Illinois should increase the size of the state name and year number to at least 1 in. as soon as possible.

12. The State of Illinois should adopt one, two, or three color combinations which are high in contrast and then alter the combinations selected with each plate issuance.

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# VIII. APPENDICES

## APPENDIX A: PHOTOMETRIC TEST FOR MEASURING THE BRIGHTNESS OF REFLEX-REFLECTING MATERIALS

The following is a description of the apparatus and the test procedure used to determine the brightness of reflex-reflecting materials in absolute units. The brightness qualities of these materials were used in the study of color combinations for license plates. This apparatus was designed to serve only that purpose and is not necessarily a standard test procedure.

### Apparatus

The apparatus consisted of a 500-watt slide projector with a constant voltage transformer to provide the light source. A 2 by 2-in. metal slide with a small hole in the center was inserted in the slide holder to provide a circular beam of light 15 in. in diameter at 20 ft. Mounted on both sides of the projection lens were two chromatically corrected photocells connected in series. The leads from the photocells were connected to a shunt which was in turn coupled with an extremely sensitive galvanometer.

A device similar to the plate holder on the test cart was used to hold the specimen plate. The five magnets on the plate holder kept the plate rigid and flat and provided for easy mounting. Provisions were made so the specimen plate could be moved both horizontally and vertically.

Figs. 30 and 31 are illustrations of the test apparatus.

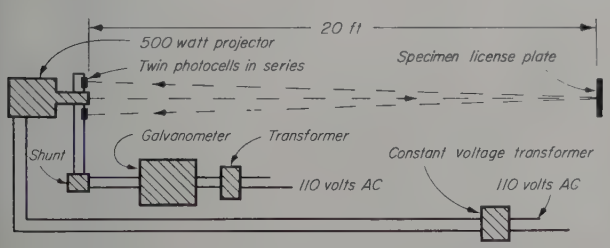


*Fig. 30. Schematic Diagram of the Apparatus for Testing the Brightness of Reflex-Reflecting Materials*

### Procedure

The tests were conducted in a completely darkened room where adequate 110-volt power supply was available. After the apparatus was set up, started, and allowed to come to equilibrium for ½ hour, the galvanometer was set to read zero with the shunt on the 1.0 sensitivity and the photocell faces covered with opaque tape.

The incident light was measured by placing the two photocells in the plane of the specimen at five positions and recording the galvanometer readings. The photocells were then returned to their positions near the projector lens and a specimen plate placed on the mounting device.

To remove the glare from the specimen plate, the mounting device was tilted upward so that the glare pattern from the plate fell about 5 in. above the faces of the photocells. With the plate mounting device secured in this position, the specimens were then mounted and the galvanometer readings recorded.

### Calculations

The brightness of the test sample was computed by dividing the apparent candlepower of the sample by the illumination on the sample and then again by the surface area of the specimen.

The illumination on the sample was computed

*Fig. 31. Photograph of the Brightness Testing Equipment in Operation*

by dividing the average of the five galvanometer readings when the photocells were in the plane of the sample by the shunt sensitivity factor.

The apparent candlepower of the sample was the galvanometer reading divided by the shunt factor times the square of the distance in feet between the light source and the test sample.

Brightness units are then in units of "candlepower per 'normal' foot-candle per square foot of sample." The angle of divergence inherent in the apparatus was approximately one degree.

The galvanometer and the photocells were checked for linearity and found not to exceed 1% variance in the range used in this test.

# APPENDIX B: DETAILS OF SPECIMEN LICENSE PLATES USED IN THE STUDY OF REFLECTORIZED PLATES

Key:

A — Flat sheeting
B — Exposed lens sheeting
C — Beads on paint
D — Semi-gloss paint
E — Aluminum paint

D/L — Dark legend on light background
L/D — Light legend on dark background

O — Opaque
R — Reflectorized

| Code Number | Plate Number | Type of Material | Contrast Direction | System of Reflectorization | Stroke Width of Digits (in.) | Color Combination | Legibility Distance (ft) Series I | Legibility Distance (ft) Series II | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| I 1 | 4759 | A | D/L | Background | 1 4/32 | O Blue on R White | 139.1 | | |
| I 2 | 9426 | A | D/L | Background | 1 3/32 | O Blue on R White | 135.1 | | |
| I 3 | 8893 | A | D/L | Background | 1 0/32 | O Blue on R White | 130.2 | | |
| I 4 | 5860 | A | D/L | Background | 8/32 | O Blue on R White | 127.2 | | |
| I 5 | 2537 | B | D/L | Background | 1 4/32 | O Blue on R White | 136.0 | | |
| I 6 | 9204 | B | D/L | Background | 1 3/32 | O Blue on R White | 134.4 | | |
| I 7 | 6977 | B | D/L | Background | 1 0/32 | O Blue on R White | 128.6 | | |
| I 8 | 3648 | B | D/L | Background | 8/32 | O Blue on R White | 128.4 | | |
| I 9 | 0365 | C | D/L | Background | 1 4/32 | O Blue on R White | 132.9 | | |
| I 10 | 7082 | C | D/L | Background | 1 3/32 | O Blue on R White | 134.5 | | |
| I 11 | 7459 | C | D/L | Background | 1 0/32 | O Blue on R White | 130.5 | | |
| I 12 | 4526 | C | D/L | Background | 8/32 | O Blue on R White | 126.3 | | |
| I 13 | 4893 | D | D/L | | 1 4/32 | O Blue on O White | 107.3 | | |
| I 14 | 8560 | D | D/L | | 1 3/32 | O Blue on O White | 103.1 | | |
| I 15 | 5237 | D | D/L | | 1 0/32 | O Blue on O White | 100.1 | | |
| I 16 | 2904 | D | D/L | | 8/32 | O Blue on O White | 98.4 | | |
| I 17 | 9673 | D | L/D | | 1 4/32 | O White on O Blue | 112.4 | | |
| I 18 | 6348 | D | L/D | | 1 3/32 | O White on O Blue | 109.8 | | |
| I 19 | 3025 | D | L/D | | 1 0/32 | O White on O Blue | 110.2 | | |
| I 20 | 0782 | D | L/D | | 8/32 | O White on O Blue | 109.5 | | |
| I 21 | 5479 | E | D/L | | 1 4/32 | O Blue on Aluminum | 107.9 | | |
| I 22 | 2046 | E | D/L | | 1 3/32 | O Blue on Aluminum | 106.6 | | |
| I 23 | 9893 | E | D/L | | 1 0/32 | O Blue on Aluminum | 103.6 | | |
| I 24 | 6580 | E | D/L | | 8/32 | O Blue on Aluminum | 103.5 | | |
| I 25 | 3257 | E | L/D | | 1 4/32 | Aluminum on O Blue | 110.0 | | |
| I 26 | 0924 | E | L/D | | 1 3/32 | Aluminum on O Blue | 114.7 | | |
| I 27 | 7698 | E | L/D | | 1 0/32 | Aluminum on O Blue | 113.5 | | |
| I 28 | 4368 | E | L/D | | 8/32 | Aluminum on O Blue | 110.2 | | |
| I 29 | 7035 | A | L/D | Legend | 1 4/32 | R White on O Blue | 147.7 | | |
| I 30 | 8702 | A | L/D | Legend | 1 3/32 | R White on O Blue | 149.9 | | |
| I 31 | 9475 | A | L/D | Legend | 1 0/32 | R White on O Blue | 150.6 | | |
| I 32 | 6642 | A | L/D | Legend | 8/32 | R White on O Blue | 147.8 | | |
| I 33 | 3859 | B | L/D | Legend | 1 4/32 | R White on O Blue | 141.6 | | |
| I 34 | 0586 | B | L/D | Legend | 1 3/32 | R White on O Blue | 142.6 | | |
| I 35 | 7253 | B | L/D | Legend | 1 0/32 | R White on O Blue | 147.4 | | |
| I 36 | 4920 | B | L/D | Legend | 8/32 | R White on O Blue | 149.5 | | |
| I 37 | 4697 | C | L/D | Legend | 1 4/32 | R White on O Blue | 144.4 | | |
| I 38 | 8364 | C | L/D | Legend | 1 3/32 | R White on O Blue | 144.4 | | |
| I 39 | 5033 | C | L/D | Legend | 1 0/32 | R White on O Blue | 145.6 | | |
| I 40 | 2708 | C | L/D | Legend | 8/32 | R White on O Blue | 148.9 | | |
| I 41 | 4975 | A | D/L | Both | 1 4/32 | R Blue on R White | 140.2 | | |
| I 42 | 2642 | A | D/L | Both | 1 3/32 | R Blue on R White | 133.8 | | |
| I 43 | 8309 | A | D/L | Both | 1 0/32 | R Blue on R White | 134.0 | | |
| I 44 | 5086 | A | D/L | Both | 8/32 | R Blue on R White | 131.1 | | |
| I 45 | 2753 | A | L/D | Both | 1 4/32 | R White on R Blue | 140.8 | | |
| I 46 | 9420 | A | L/D | Both | 1 3/32 | R White on R Blue | 142.6 | | |
| I 47 | 6997 | A | L/D | Both | 1 0/32 | R White on R Blue | 141.5 | | |
| I 48 | 3864 | A | L/D | Both | 8/32 | R White on R Blue | 148.8 | | |
| I 49 | 0538 | B | D/L | Both | 1 4/32 | R Blue on R White | 135.0 | | |
| I 50 | 7208 | B | D/L | Both | 1 3/32 | R Blue on R White | 130.5 | | |
| I 51 | 7945 | B | D/L | Both | 1 0/32 | R Blue on R White | 131.1 | | |
| I 52 | 4672 | B | D/L | Both | 8/32 | R Blue on R White | 127.6 | | |
| I 53 | 6389 | B | L/D | Both | 1 4/32 | R White on R Blue | 139.7 | | |
| I 54 | 8056 | B | L/D | Both | 1 3/32 | R White on R Blue | 136.4 | | |
| I 55 | 5723 | B | L/D | Both | 1 0/32 | R White on R Blue | 143.1 | | |
| I 56 | 2490 | B | L/D | Both | 8/32 | R White on R Blue | 139.8 | | |
| I 57 | 9567 | C | D/L | Both | 1 4/32 | R Blue on R White | 138.8 | | |
| I 58 | 6834 | C | D/L | Both | 1 3/32 | R Blue on R White | 134.4 | | |
| I 59 | 3504 | C | D/L | Both | 1 0/32 | R Blue on R White | 129.4 | | |
| I 60 | 0278 | C | D/L | Both | 8/32 | R Blue on R White | 132.6 | | |
| I 61 | 5947 | C | L/D | Both | 1 4/32 | R White on R Blue | 140.8 | | |
| I 62 | 2634 | C | L/D | Both | 1 3/32 | R White on R Blue | 140.4 | | |
| I 63 | 9382 | C | L/D | Both | 1 0/32 | R White on R Blue | 141.0 | | |
| I 64 | 6050 | C | L/D | Both | 8/32 | R White on R Blue | 132.5 | | |
| II 1 | 7548 | A | D/L | Background | 1 4/32 | O Blue on R White | 121.4 | 132.7 | 1½-in. spacing |
| II 2 | 4235 | A | D/L | Background | 1 4/32 | O Blue on R White | 110.9 | 121.2 | 1½-in. spacing |
| II 3 | 2982 | A | D/L | Background | 1 4/32 | O Blue on R White | 106.7 | 116.6 | 1½-in. spacing |
| II 4 | 8659 | A | D/L | Background | 1 4/32 | O Blue on R White | 102.7 | 112.3 | 1½-in. spacing |
| II 5 | 6253 | A | D/L | Both | 1 4/32 | R Red on R Yellow | | 110.7 | |
| II 6 | 3920 | A | D/L | Both | 1 4/32 | R Blue on R Yellow | | 137.9 | |
| II 7 | 0697 | A | D/L | Both | 1 4/32 | R Green on R Yellow | | 129.5 | |
| II 8 | 7364 | A | D/L | Both | 1 4/32 | R Red on R White | | 128.9 | |
| II 9 | 4039 | A | D/L | Both | 1 4/32 | R Orange on R White | | 109.3 | |
| II 10 | 8708 | A | D/L | Both | 1 4/32 | R Green on R White | | 133.3 | |
| II 11 | 8475 | A | D/L | Both | 1 4/32 | R Blue on R Orange | | 139.6 | |
| II 12 | 5742 | A | D/L | Both | 1 4/32 | R Green on R Orange | | 132.7 | |
| II 13 | 2869 | A | L/D | Both | 1 0/32 | R Yellow on R Red | | 116.1 | |
| II 14 | 9586 | A | L/D | Both | 8/32 | R Yellow on R Blue | | 149.2 | |
| II 15 | 5326 | A | L/D | Both | 1 0/32 | R Yellow on R Green | | 121.8 | |
| II 16 | 2093 | A | L/D | Both | 8/32 | R White on R Red | | 124.2 | |
| II 17 | 9760 | A | L/D | Both | 1 0/32 | R White on R Orange | | 93.0 | |
| II 18 | 6437 | A | L/D | Both | 8/32 | R White on R Green | | 130.9 | |
| II 19 | 3504 | A | L/D | Both | 8/32 | R Orange on R Blue | | 146.9 | |
| II 20 | 0874 | A | L/D | Both | 8/32 | R Orange on R Green | | 132.0 | |
| II 21 | 3974 | A | D/L | Background | 1 3/32 | O Blue on R White | 113.3 | 123.8 | 1½-in. spacing |
| II 22 | 7349 | A | D/L | Background | 1 3/32 | O Blue on R White | 123.9 | 135.4 | 2-in. spacing |
| II 23 | 0642 | A | L/D | Legend | 8/32 | R White on O Blue | 108.9 | 119.1 | 1½-in. spacing |
| II 24 | 4526 | A | L/D | Legend | 8/32 | R White on O Blue | 138.6 | 151.4 | 2-in. spacing |
| II 25 | 4973 | A | D/L | Background | 1 4/32 | O Blue on R White | 118.5 | 129.6 | 1¾-in. spacing |
| II 26 | 2564 | A | L/D | Legend | 8/32 | R White on O Blue | 128.6 | 140.7 | 1¾-in. spacing |
| II 27 | 4759 | A | D/L | Background | 1 4/32 | O Blue on R White | 132.1 | 144.4 | With O Border |
| II 28 | 9745 | A | L/D | Legend | 8/32 | R White on O Blue | 145.9 | 159.5 | With R Border |
| II 29 | 5749 | A | L/D | Legend | 8/32 | R White on O Blue | 148.8 | 162.7 | Check plate |
| II 30 | 4920 | A | L/D | Both | 8/32 | R White on R Blue | 141.7 | 154.9 | Check plate |
| II 31 | 2839 | C | L/D | Both | 8/32 | R White on R Blue | 135.9 | 148.6 | Check plate |
| II 32 | 6834 | C | D/L | Both | 1 3/32 | R Blue on R White | 134.4 | 146.2 | Rerun same as I-58 |
| II 33 | 8056 | B | L/D | Both | 1 3/32 | R White on R Blue | 136.4 | 149.9 | Rerun same as I-54 |
| II 34 | Omitted | | | | | | | | |
| II 35 | 7592 | A | L/D | Legend | 8/32 | R Orange on O Black | | 161.8 | |
| II 36 | 5248 | A | D/L | Background | 1 4/32 | O Black on R Yellow | | 143.4 | |

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